Mr. Robert F. Smallcomb, Jr.
Director
Pipeline Engineering and Safety Division
The Commonwealth of Massachusetts
Department of Public Utilities
100 Cambridge Street
Boston, Massachusetts 02202

Dear Mr. Smallcomb:

Your letter of July 31, 1996, describes the Massachusetts Department of Public Utilities (MDPU) evaluation and approval of an application by Bay State Gas Company of Lawrence, Massachusetts for waiver of 49 CFR 192.321(a). Section 192.321(a) requires that plastic pipe used in gas distribution service must be installed below ground level.

The waiver request reflects Bay State Gas Company's desire to reactivate a previously operative 8-inch steel gas service line by insertion of a 6-inch high density polyethylene pipe using the existing steel pipe as a casing. A portion of the proposed line will be installed in a utility bay beneath a rail road bridge. The total inserted polyethylene pipe length is 180 feet and is protected adequately by fiberglass pipe shields. As suggested by the MDPU, the inner pipe is supported by spacers to prevent abrasion that may result from contact with the casing, The line pressure is 0.S psig.

Based on the information provided by Bay State Gas Company, and your evaluation of operating conditions of the proposed service line, the Office of Pipeline Safety (OPS) concurs with you that the waiver will not be inconsistent with pipeline safety regulations and will not be detrimental to public safety. For this reason, OPS will not object to the waiver as granted by the MDPU.

Sincerely,
Richard B. Felder
Associate Administrator for Pipeline Safety

The Commonwealth of Massachusetts
Department of Public Utilities
100 Cambridge Street
Boston, Massachusetts 02202

July 31, 1996

Richard B. Felder
Associate Administrator for Pipeline Safety (DPS-1)
Research and Special Programs Administration
Department of Transportation
400 Seventh Street, SW.
Washington, D.C. 20590

RE: Waiver of Pipeline Safety Regulations

Dear Mr. Felder:

Being a certified agent under section 60105, Public Law 103-272, the Massachusetts Department of Public Utilities ("MDPU") has approved a waiver to Bay State Gas Company ("Bay State") from the requirements of Tie 49 C.F.R. Part 192, § 192.321(a). The waiver allows Bay State to install 180 feet of 6 Plexco 3408 high density polyethylene gas pipe into an 8" bare steel casing. Of that length, 140 feet will span a bridge and therefore, will not meet the burial requirements of § 192.321(a).

The 8" steel casing is a former gas carrier beneath a bridge which spans a railroad track operated by the Massachusetts Bay Transit Authority. The line was abandoned in 1987. The abandoned carrier is connected to an 8" cast iron pipe on each side of the bridge.

The inserted plastic carrier pipe will operate at a pressure of 0.5 PSIG. The casing and carrier will be located below the bridge, thus out of direct sunlight. Bay State has submitted extensive calculations which demonstrate the minimal effects of temperature on the plastic carrier.

As required by section 60118(d), Public law 103-272, I am forwarding a copy of the waiver to your office with the understanding that the waiver will be effective within 60 days of notification unless the Secretary objects to the waiver in writing before the effective date.

Thank you for your support in this matter.

Very truly yours,
Robert F. Smallcomb r. Director
Pipeline Engineering and
Safety Division

The Commonwealth of Massachussetts
Department of Public Utilities
Leverett saltonstall Building, Government Center
100 Cambridge Street
Boston 02202

July 31, 1996

Mr. Michael Laghetto
Bay State Gas Company P.O. Box 869
Lawrence, MA 01841-2312

RE: Waiver of Pipeline Safety Regulations

Dear Mr. Laghetto:

I have reviewed Bay State Gas Company's ("Bay State") application for a waiver from the provisions of Title 49 C.F.R. Part 192, § 192.321(a) and § 4.18 of Bay State's Operating and Maintenance Plan which require that plastic pipe be installed below ground.

In the application you presented a strong argument to demonstrate that the proposed installation of encased plastic pipe attached to the underside of a bridge on Salem Street, Lawrence would not be detrimental to public safety. In addition to providing the information required in 220 C.M.R. § 101.06(10), Protection from Hazards, you have presented a plan which demonstrates that the plastic pipe will be protected from traffic, contractors, ultraviolet radiation, temperature extremes and thermal stresses. The only modification to the proposal is that Bay State employ casing spacers or equivalent means to protect the carrier pipe from abrasion in place of fiberglass pipe shields.

Based upon your request, I have decided that a waiver of the federal regulation set forth in § 192.321(a) and the attendant sections of Bay State's Operating and Maintenance Plan would not pose a threat to pipeline safety for the following reasons:

(1) The plastic pipe will be protected from the ultraviolet radiation of direct sunlight.

(2) The steel casing will protect the pipe from external forces such as traffic and excavators.

(3) Situated beneath the bridge, the casing and carrier pipe will not be subjected to excessive heat caused by exposure to direct sunlight.

(4) Gas flow will further moderate the expected temperature extremes ranging from -20°F to 100°F.

(5) The operating pressure of the pipeline will be 0.5 psig.

(6) Thermal variations pose no threat to the integrity of the carrier pipe.

Having approved the waiver as authorized under § 60118(c) of Public Law 103-272, the effective date will be 60 days from the date of this approval in which time the Secretary of the Department of Transportation may issue a written objection to the waiver under § 60118(d) of the same title.

Very truly yours,
Robert F. Smallcomb, Jr.
Director
Pipeline Engineering and Safety Division

EXHIBIT A
BAY STATE GAS COMPANY WAIVER APPLICATION

Bay State Gas Company

July 2, 1996

Mr. Smailcomb
Director
Pipeline Engineering and Safety Division
Department of Public Utilities
100 Cambridge St.
Boston, MA 02202

Dear Mr. Smallcomb;

Bay State Gas Company, 300 Friberg Parkway, Westborough, Massachusetts, 01581, requests a waiver of compliance with the burial requirements of 49 CFR 192.321.(a) and its own Operating and Maintenance Procedures section 4.18,Ito allow installation of polyethylene pipe inserted inside a steel casing in a utility bay beneath a bridge.

The site of this installation is beneath a bridge on Salem Street in Lawrence, Massachusetts. The bridge spans a railroad track owned by the MBTA. (See Exhibit A).

The installation consists of the insertion of approximately one hundred forty (140) feet of 6" Plexco 3408 high density polyethylene gas carrier pipe into an 8" steel casing which at one time was used as a gas carrier but has been inactive since 1987. The 8" steel is joined with 8" cast iron pipe before each bridge abutment (underground). In 1987, joint leaks on the 8" cast iron pipe caused the 8" cast iron approaching the bridge and therefore the 8" steel on the bridge to be taken out of service. The 8" steel on the bridge is joined by a Dresser coupling as it penetrates each headwall above ground. All joints between the two Dresser couplings are welded. The 8" steel will be inserted approximately twenty (20) feet beyond each approach slab which will make the total length to be inserted one hundred eighty (180) feet. The inserted polyethylene pipe will be protected by fiberglass pipe shields placed a minimum of five feet apart to ensure that the polyethylene pipe does not come in contact with the steel casing. Link seals will be placed at each end to seal the casing. *The* 8" steel casing is currently supported approximately every twelve (12) feet.

The Plexco 3408 high density polyethylene pipe used in the bridge crossing will be joined by butt fusion and as a result will require no fittings within the bridge span. Nordstrom high density polyvalves will be installed within twenty five (25) feet of each side of the bridge in readily accessible locations.

The exposed portion of the casing is within a utility bay underneath the bridge structure and will not be exposed to any direct sunlight.

Pressure ratings for high density polyethylene at various temperatures are shown in Table 1 (Exhibit B). The high density polyethylene pipe will be pressure tested at 150 psi. Actual operating pressure will be significantly less than design pressure as it is located in a low pressure distribution system.

Polyethylene pipe which is inserted into a casing on a bridge crossing will experience more rapid changes in temperature than polyethylene pipe that is buried below ground. For this reason, care should be taken to ensure that the temperature changes will not cause the pipe to experience a thermal stress greater than the yield strength of the pipe. The ability of polyethylene pipe to withstand the force of thermal contraction and expansion is dependent on its modulus of elasticity which changes with the temperature.

Extreme weather data for the past 25 years was obtained from Weather Services Corporation in Lexington, Massachusetts. Data obtained was from their Bedford, Massachusetts station which from a meteorological perspective is virtually identical to that of Lawrence, Massachusetts. The extreme high temperature was 103° F which occurred on August 2, 1975 and the extreme low temperature was -10° F which occurred on December 25, 1980. It should be noted that studies have been conducted which show that the flowing gas temperature within the plastic pipe cools the gas carrier pipe when the ambient temperature is high and heats the gas carrier pipe when the ambient temperature is low. The heating and cooling effect lessens the extreme high and low temperatures the plastic gas carrier will experience and thereby reduce expansion and contraction. (See "Design Considerations for PE Bridge Crossings" by Jay W. Brandi, San Diego Gas & Electric, presented at the American Gas Association Operations Conference in Montreal, Canada; May 1996). (See Exhibit C).

The 8" steel casing in our installation will be located out of direct sunlight, and the anticipated temperature range inside the casing should not exceed -20° F to 100° F. Assuming the installation were made at 80° F and then instantaneously cooled to -20° F, the most extreme condition neglecting the heating and cooling effects of the natural gas, the plastic main in the bridge would experience an instantaneous calculated thermal contractive stress of 2400 psi. which has a safety factor of 2.16

In reality, dramatic changes in ambient temperature are not instantaneous. Nor will they lead to equivalent changes in the temperature of the polyethylene. The pipe location, (under the bridge, in a steel casing), combined with the warming effect created by the flowing gas temperature, will mitigate the effects of changes in ambient temperature.

While the modulus of elasticity of polyethylene changes with temperature, it will also experience a relaxing of stress with time. This relaxation is estimated to be approximately 47% for temperature fluctuations with time in this bridge installation. As can be seen from the table, a relaxation of stress of 47% occurs after only 10 hours which is extremely conservative considering an assumed temperature change of 100° F. (See Exhibit D).

The relaxed thermal contracted stress is calculated to be 1128 psi. This stress level is well within acceptable stress limits with a safety factor of 4.60. (See Exhibit B).

An examination of the combined stress calculations show that hoop stress and radial stress are negligible compared to the longitudinal stress due to contraction

In conclusion, there will be no special anchoring or expansion joints required for this installation, therefore, Bay State Gas Company requests a waiver of compliance with the burial requirements of 49 CFR 192.321. (a) and its own Operating and Maintenance Procedures section 4.18, to allow the installation of polyethylene pipe inserted inside a steel casing in a utility bay beneath a bridge based on the following:

1) The polyethylene will be inside a steel casing which will protect it from traffic, contractors, the sun, and any other outside forces which could damage the polyethylene.
2) The steel casing is in a utility bay beneath a bridge and is protected from exposure to direct sunlight which otherwise may cause the polyethylene within the casing to be exposed to higher than normal temperatures.
3) Flowing gas temperature will tend to warm the polyethylene in the winter and cool it in the summer to even further reduce the risk of excessive temperature exposure.
4) The gas pressure within the polyethylene is low pressure and produces no significant stresses on the polyethylene.
5) A conservative estimate of the relaxed thermal stress due to fluctuations in temperature is calculated to be 1128 psi. which produces a safety factor of 4.60.

Bay State Gas Company appreciates the Department's consideration of this matter. Should the Department require clarification or additional information, please feel free to contact me at 508-580-0100 ext. 1442.

Very Truly Yours

Michael Laghetto

EXHIBIT B

BAY STATE GAS COMPANY WAIVER APPLICATION

Specifications:

Pipe:	Plexco PE 3408 High Density Polyethylene Pipe
Nominal Size:	6 inch IPS
SDR:	11
Fittings:	6 inch Nordstrom High Density Polyvalves
Length:	50 feet
Sleeve:	8 inch steel

Operating pressure:	$P = 0.5$ psig
Pipe outside diameter:	$D = 6.625$ inches
Pipe wall thickness:	$t_w = 0.602$ inch
Tensile yield strength:	$S_y = 3{,}500$ psi
Modulus of elasticity:	$E = 110{,}000$ psi
Coefficient of thermal expansion:	$a = 8 \times 10^{-5}$ in./(in.)(°F)
Long term hydrostatic strength:	$S = 1600$ psi @ 73°F

Maximum Operating Pressure at Various Temperatures:

$$P_{max} = 2S\{t_w/(D-t_w)\} \times 0.32$$

TABLE 1

For Pressure Ratings at	Multiply 73°F Rating By	Long Term Hydrostatic Strength (S)	Operating Pressure
40°F	1.2	1920 psi	100 psig*
60°F	1.08	1728 psi	100 psig*
73°F	1	1600 psi	100 psig*
100°F	0.78	1248 psi	79.8 psig
103°F	0.76**	1216 psi	77.8 psig
120°F	0.63	1008 psi	64.5 psig
140°F	0.5	800 psi	51.2 psig

* Title 49 CFR part 192.123(a) limits gas pressure in thermoplastic pipe to 100 psig

** Value interpolated from nearest known values.

Circumferential Hoop Stress:

$$\sigma_H = F/A = Pr/t$$

where P = operating pressure of PE pipe (psig)
r = inside radius of PE pipe (inches)
t = wall thickness of PE pipe (inches)

therefore:

$$\sigma_H = Pr/t$$
$$= (0.5)(2.7105)) / (0.602)$$
$$= 2.25 \text{ psi}$$

Longitudinal Stress (Thin Wall Pressure Vessel Formula):

$$\sigma_L = Pr/2t$$
$$= (0.5)(2.7105)\} / \{(2)(0.602)$$
$$= 1.13 \text{ psi}$$

Longitudinal Stress Due to Thermal Contraction:

Assume initial pipe temperature: T_i = 80°F
Assume coldest temperature of pipe: T_f= -20°F

$\Delta T= T_i - T_f$
ΔT= (-20°F) - 80°F
ΔT= -100 °F

Strain due to Temperature Change:

$\epsilon_r = a\Delta T$
$\epsilon_r = \{8 \times 10^{-5}$ in./(in.)(°F)}{-100 °F}
ϵ_r = -0.008 in./(in.)

Longitudinal Thermal Stress (Instantaneous Value):

$\sigma_{LT} = \epsilon_r E$

where E= 300,000 psi @ -20°F

σ_{LT} = (-0.008 in./(in.)) (300,000 psi)
σ_{LT} = -2400 psi

Reduced Stress After Relaxation With Time:

$\sigma_{LT} = \epsilon_r E^1$

where E^l= 47% of E= 141,000 psi
σ_{LT} = {-0.008 in./(in.)}{ 141,000 psi}
$\sigma_{LT.}$ = -1128 psi

Hoop Stress: $S_1 = \sigma_H$
Longitudinal Stress: $S_2 = \sigma_L \; \sigma_{LT}$
Radial Stress: $S_3 = -P$

Total Combined Stress (Instantaneous Value):

$$S_o = (S_1^2+S_2^2+S_3^2-S_1S_2-S_2S_3-S_3S_1)^{1/2}$$

Where $S_1 = 2.25$ psi
$S_2 = (1.13-2400) = -2398.87$ psi
$S_3 = -0.5$ psi

$S_o= [(2.25)^2+(-2398.87)^2+(-0.5)^2-(2.25)(-2398.87)-(-2398.87)(-0.5)-(-0.5)(2.25)]^{1/2}$

$S_o = 2399.75$ psi

$S_y = 5184$ psi

Safety Factor = (5184/2399.75) = 2.16

Total Combined Stress After Relaxation:

$$S_o= (S_1^2+S_2^2+S_3^2-S_1S_2-S_2S_3-S_3S_1)^{1/2}$$

where $S_1 = 2.25$ psi
$S_2 = (1.13-1128) = -1126.87$ psi
$S_3 = -0.5$ psi

$S_o = [(2.25)^2+(-1126.87)^2+(-0.5)^2-(2.25)(-1126.87)-(-1126.87)(-0.5)-(-0.5)(2.25)]^{1/2}$

$S_o = 1127.74$ psi

$S_y = 5184$ psi

Safety Factor = (5184/1127.74) = 4.6

Total Combined Stress Without Thermal Contraction:

$$S. = (S_1^2+S_2^2+S_3^2-S_1S_2-S_2S_3-S_3S_1)^{1/2}$$

where $S_1 = 2.25$ psi
$S_2 = 1.13$
$S_3 = -0.5$ psi

$S_o = [(2.25)^2+(+1.13)^2+(-0.5)^2-(2.25)(1.13)-(1.13)(-0.5)-(-0.5)(2.25)]^{1/2}$

$S_o = 2.40$ psi

$S_y = 3200$ psi

Safety Factor = (3200/2.40) = 1333

EXHIBIT C

BAY STATE GAS COMPANY WAIVER APPLICATION

Design Considerations
for
PE Bridge Crossings

By
Jay W. Brandli
Gas Distribution Engineer
San Diego Gas & Electric, An Enova Company

Presented at the
American Gas Association Operations Conference
Montreal Canada; May 1996

Abstract

This paper presents key equations and concepts that relate to the installation of polyethylene gas pipe on bridge structures. It is assumed that the reader has a working knowledge of PE gas pipe design and is familiar with the basic mechanics surrounding a bridge crossing. Issues with regard to economics, thermal phenomena (actual temperatures, thermal stresses and strains), dynamic loading (vehicular and seismic), and bridge design are presented.

Nomenclature

P	Operating pressure of PE pipe (psig)
MAOP	Maximum allowable operating pressure (psig)
HDB	Hydrostatic design basis (psi)
SDR	$\frac{D}{T}$
D_m	Mean diameter (in)
D_o	Outside diameter of PE pipe (in)
t	Wall thickness of PE pipe (in)
f_s	Design factor per 192 DOT-.32
F_T	Temperature derating factor
T	Instantaneous temperature (°F)
T_I	Installation temperature
E	Modulus of elasticity (psi)
E_{50yr}	Long term modulus)spi)
$\Delta T = (T - T_I)$	Change in temperature (°F)
T_L	Low temperature °F
	Coefficient of thermal expansion (in/in/°F)
ϵ	Strain (in/in)
F	Force (lb)
L_f	Lag factor (typically 1.25 -1.5)
L	Length (in)
L_o	Initial length (in)
ΔL	Change in length (in)
δ	Lateral displacement/deflection (in)
P_L	Dynamic load pressure (psi)
W_L	Wheel load (lb) (typically 16,000 lb for H-20 wheel)
W_P	Weight of pipe (lb/in)
A_c	Contact area (ft^2) (typically 2.5 ft^2 for H-20 wheel)
A	Pipe cross sectional area (in^2)
H	Depth of cover (ft)
I_1	Impact load factor (typically 1.5 for rigid pavement)
r_e	Equivalent radius (ft)
I	Moment of inertia (in^4)
ΔX	Deflection (in)
K	Bedding factor (0.1)
E’	Soil reaction modulus (psi) typically 1,000 - 3,000 depending upon soil type and percent compaction

Design Considerations for PE Bridge Crossings

Cost Savings

The main motivation for the use of PE in bridge crossings is economic in nature. PE will perform as safely as steel at a much lower lifetime cost.

<u>Capital</u>

PE Pipe Costs Less Than Steel

Typical Unit Costs

Diameter	Steel	PE	Savings
2”	$1.80	$0.41	$1.39
4”	$3.57	$1.38	$2.19
6”	$4.98	$2.95	$2.03

PE Costs Less To Install

- PE weighs less than steel, therefore handling costs are reduced.
- Pipe is fused as opposed to welded, which is faster.
- Pipe is available in continuous coils, thus eliminating the costs associated with joining the pipe prior to installation through the bridge.

<u>O&M</u>

Cathodic Protection Costs Are Eliminated

- PE pipe does not corrode, therefore the costs associated with joint coating, jeeping, and regular cathodic protection are eliminated.
- Any cathodically protected carrier pipe inside a steel casing is subject to the possibility of shorting.
- The installation of a steel bridge crossing in an otherwise all plastic piping system could generate buried isolated steel sections that must be cathodically protected and regularly surveyed to assure that a satisfactory level of protection is maintained.

<u>Maintenance</u>

A damaged section of PE is easily shut down (squeezed off) and repaired quickly, with little impact to the customer base. Damaged steel often requires valve closures and welding to repair.

Estimated Cost Savings

To date SDG&E has installed two PE bridge crossings and has three more currently under design.

Bridge Type	Carrier Size	Casing Size	Length	Estimated Savings
Closed Cell	2"	4" Steel	112'	5.4%
Closed Cell	4"	8" Steel	98'	14.8%

Basic Types of Bridge Structures

Box-Culvert.

Box-Culvert crossings are designed as a typical portion of the underground piping.

Existing:

If the designer is attempting to cross an existing bridge structure, the pipe will usually be installed externally, inside a casing, that is attached to the bottom or side of the bridge deck. Installation of PE pipe on wooden (flammable) bridge structures is not recommended.

**See original for Figures 1 & 2

New

If a new bridge is being installed it is preferable to cross the bridge internally. The utility designer coordinates with the Bridge Designer as well as the Bridge Contractor to determine how the bridge will be crossed. The two most common types of bridge decks are Box Girder and Solid Slab.

**See original for Figures 3 & 4

Areas of Design Analysis

Ultra Violet (UV) Radiation: PE pipe with a carbon black content of less than 2% must be protected from UV radiation.

Vandalism: PE pipe is not as tough as steel. If the pipe is accessible by the public it must have some type of mechanical protection to eliminate the possibility of damage by vandalism.

Operating Pressure: The HDB of PE pipe decreases as temperature increases, thus the higher the temperature for a given SDR, the lower the MAOP of the line.

Thermal Effects: As the temperature of the pipe changes from its initial installation temperature, the pipe will be subjected to thermal expansion and contraction. Unrestrained PE pipe will elongate (or shrink) by approximately 1 inch per 100 feet of pipe for every 10°F change in temperature. If the pipe is restrained, longitudinal stresses will develop within the pipe wall.

Dynamic Loading: The two most commonly encountered forms of dynamic loading are seismic and vehicular. If a seismic event is anticipated, the carrier (whether PE or steel) must be designed to withstand the anticipated displacements (longitudinal and transverse) and their accompanying accelerations. Excessive stresses may also develop under the bricoe approaches if shallow pipe is exposed to heavy traffic loading. The use of casings is often employed to reduce the stresses generated by dynamic loading.

Bridge Constraints: Many factors affecting the overall design of the crossing, i.e., abutment openings. approach slabs, differential settlement, etc., will be governed by the site specific bridge plans.

All of the above mentioned items should be addressed when designing a bridge crossing with PE pipe. It is essential to remember that unlike the modulus for steel, polyethylene's modulus of elasticity varies greatly as a function of temperature and rate of strain. Optimum designs will take into account the effects from stress relaxation or creep.

Detailed Analysis of Major Design Parameters

UV Radiation and Vandalism: PE pipe is usually installed in a casing or structure that limits access to the pipe.

Operating Pressure: The equation that determines the Maximum Allowable Operating Pressure (MAOP) of a PE gas line is:

$$P = \frac{2 \times HDB \times f_s \times f_r}{SDR-1}$$

Table 1 shows common values used for the temperature derating factor (f_r.), for PE 2406 (medium density) and PE 3408 (high density) materials.

Table 1. Temperature Derating Factors

Temperature °F	PE 2406	PE 3408
60	1.04	1.08
73	1.00	1.00
90	0.95	0.86
100	0.92	0.78
120	0.86	0.63
140	0.80	0.50

The variation of maximum allowable operating pressures (as a function of temperature) is shown in Figure 5 for SDR 13.5 and 11.5, PE 2406 and PE 3408 materials.

**See original for Figure 5

The values in Figure 5 have been calculated for continuous use at the elevated temperatures. Each geographic location must be analyzed to determine the maxim operating temperature that will be encountered by the PE Once a maximum temperature has been defined, the proper material and wall thickness can then be selected. It should be hated the effects of temperature cycling to a maximum temperature are less detrimental than continuous operation of the pipe at a given elevated temperature. Short terra excursions to temperatures slightly above the maximum continuous use temperature (for a given operating pressure) should not be of great concern to the designer—they are usually accounted for by the 0.32 design factor in the PE design equation.

PE gas pipe may only be used at the maximum temperature for which it has been awarded a hydrostatic rating by the manufacturer and may never be operated at temperatures exceeding 140 ^{0}F.

Thermal Effects

PE pipe in or on a bridge structure is a complex heat exchanger (naturally convecting, single pass, shell and tube) with natural gas entering at the ground temperature being heated by radiative and convective heat transfer and then returning to ground temperature when the pipe reenters the ground.

The temperature of the PE pipe will always tend to lag behind and remain lower than the ambient temperature during normal daily cycling. This effect is demonstrated in Figure 6 for a relatively cold day in January 1996 and in Figure 7 for a warm day in April, 1996. The temperatures were obtained from a 112 foot 2-inch PE carrier inside a flinch steel casing in the south part of San Diego County, less than a mile from the coast

**See original for figures 6 & 7

Two types of thermal effects should be anticipated:

1. Stress (if the pipe is restrained) and;
2. Movement

As the temperature of the pipe varies from its installation temperature it will tend to expand (temperature increasing) and contract (temperature decreasing). Although the total thermal movement for PE pipe is much greater than that of steel, the resulting stress (induced in the pipe wall) is much lower than steel. If the pipe is restrained (regularly along the span or only as the pipe enters the soil), thermal stresses and/or deflections may develop.

Because the modulus of PE is temperature and time dependent it is critical to use the correct modulus when calculating any dynamic properties. Table Il depicts typical modulus values for PE 2406.

Table II: PE 2406 Typical Design Modulus, 10^3 PSI

Duration	-20 F°	40 °F	100 °F	140 °F
Instantaneous	240.0	88.0	80.0	58.2
10 hr	125.5	46.0	41.8	30.4
1000 hr	95.5	35.0	31.8	23.1
1 yr	82.9	25.3	27.6	20.1
50 yr	61.6	22.6	20.5	14.9

(Modulus values should be used only for thermal movement. Specific modulus values, for other calculations, should be obtained from the manufacturer.)

Thermal Expansion and Contraction:

If the PE is unrestrained it can be expected to elongate (or contract) by AL as the temperature increases above its installed temperature according to the following equation:

$$\Delta L = L_o \times a \times (T - T_1)$$

If the instantaneous temperature is greater than the installation temperature a is positive indicating that the pipe is expanding. If the pipe expands (and the span between two fixed supports is unrestrained) Euler column buckling may result. The lateral deflections can be calculated as follows:

$$\delta \approx L_o \text{ X } \sqrt{\tfrac{1}{2} \text{ X a X } \Delta T}$$

The strain induced in the pipe wall can be calculated from the following equation:

$$\epsilon = \frac{Dx\text{-}196xaxAT}{L_o}$$

Conservative designs will limit the thermal strain to less than 5%.

All pipe supports should be designed to fully accommodate or restrain lateral expansion and contraction.

Thermal Stresses:

If the instantaneous temperature drops below the installed temperature and the pipe is restrained, thermal stresses will develop according to the following formula:

$$\sigma = E_0 \text{ x a x } \Delta T$$

Using the above equation with the instantaneous modulus and the coefficient of expansion corresponding to the lower temperature will produce a conservative determination of stress. Under actual conditions the temperature changes are gradual and stress relaxation will occur, producing actual stress values that are about half of the stress predicted by the above equation. The stresses found in PE pipe are about 5-10% of the values found in steel pipe for equivalent temperature swings. Although the stresses are lower in PE, the cross sectional area is much larger, producing an overall force that is much larger than would be encountered for a similar steel system. These forces may create large stresses in other pipeline appurtenances i.e., anchors, fittings, and transitions. The forces (generated by the thermal stresses) can be calculated as follows:

$$F = \sigma \text{ x } A = \Delta T max \text{ x a x } E \text{ x } A$$

Dynamic Loading:

Seismic loading can initiate shear in areas where pipe passes through abutments or piers. Heavy traffic loading under the bridge approach may create high stress levels if a portion of the pipe has less than 18 inches of cover. Many designs rely on the use of casings to reduce the amount of dynamic loading experienced during heavy traffic at shallow depths or during a seismic event.

Seismic Loading:

When a new bridge is being designed, seismic analysis will determine anticipated displacements in the longitudinal and transverse directions. The annular space in the casing should be sized to accommodate any transverse displacement, without deforming the PE pipe. If the shearing action of the casing on the carrier causes displacements greater than can be accommodated by the annular space, additional analysis of the shearing stresses must be performed. Most designs can safely account for transverse seismic displacements with an annular space large enough to absorb most of the displacement. Unpressurized PE is capable of at least 800% elongation prior breaking to failure. This ability to stretch without rupture reduces the possibility of incurring a catastrophic failure during a seismic event.

Vehicular Loading:

If the carrier is uncased (in a slab bridge deck structure) or shallow (after exiting the abutments) the effects of vehicular loading on the pipe should be considered. To safely account for the dynamic loads that may be imparted

by an H-20 vehicle, the pipe should always have at least 18' of cover. If this is not possible (when the pipe is exiting an abutment or is under (or in) an approach slab) the stresses and strains should be analyzed to determine if additional protection for
the PE carrier is required. If the pipe is uncased and has less than 18' of cover, Timoshenku's equation for distributed loads may be used to calculate the dynamic impact loading imparted to the pipe crown by vehicular loading.

Pipe deflection can be calculated using Spangler's Modified Iowa Formula:

$$P_L \approx \frac{I_1 \times W_L}{A_c} \left[1 - \frac{H^3}{(r_E^2 + H^2)^{15}} \right] \qquad r_E = \sqrt{\frac{A_c}{\pi}}$$

$$\frac{\Delta X}{D_M} = \frac{P_L}{144} \times \left[\frac{K \times L_f}{\frac{2 \times E}{3} \times \left[\frac{1}{SDR-1}\right]^3 + 0.061 \times E'} \right] \qquad D_m = D_o - 1.06 \times t$$

Typical, Conservative, deflection limits are: $\frac{\Delta X}{D_M} \leq \begin{cases} 0.04 & SDR\ 13.5 \\ 0.03 & SDR\ 11.0 \end{cases}$

Bridge Constraints:

A bridge designer must be aware of many site specific items. Some of the major items that will affect the crossing design are:

- The allowable openings in the bridge and abutments;
- The possibility of differential settlement;
- Support and hanger spacing; and
- Floatation of pipe during the pouring of slab bridge decks.

Differential Settlement:

Settlement may occur after a new bridge has been constructed— leading to additional stresses on the carrier where it exits the abutments (or the casing) and enters the surrounding soil. Additional shielding, annular spacing, or other devices to prevent settlement may be required.

Openings and Abutments:

The Bridge Designer will often establish the maximum size opening that will be allowed through the abutments, piers or deck. This limits the maximum diameter that may be installed through a new bridge. If the openings are not of sufficient size, the pipe may be hung on the bridge after its completion.

If the pipe is shallow coming out of the abutments the designer must determine how the pipe is to transition to normal depths of cover. If fittings are not used, the maximum bend radius to attain the proper depth should not be less than 20 times the diameter of the pipe.

Hanger and Support Spacing:

Support spacing for the carrier or casing will often be determined by the allowable amount of sag and the bridge design. To determine support spacing for hangers or skids it is necessary to define the allowable deflection between supports and then calculate the required spacing. The following equation can be used to conservatively determine support spacing:

$$L_s \approx \sqrt[4]{\frac{384 \times E_{50\,yr} \times I \times y}{5 \times W_p}}$$

Supports, hangers and clamps should be designed to accommodate longitudinal movement or to withstand the forces required to fully restrain the pipe during thermal movement. Elastomeric padding should be used to shield the PE pipe wall from any rigid supports that may be damped to the pipe. The width of any restraint or support should be a minimum of half the diameter of the pipe being contacted. If unrestrained PE is entering a rigid structure (such as an abutment) it should be restrained one to three pipe diameters away from the point of transition to the structure.

Casings:

Many times the designer will wish to install a casing for the carrier pipe. The casing size and annular spacing must be appropriately sized, and suitable materials must be specified:

- Casing material:
- Casing insulators;
- End seal materials (casing boots must be designed to accommodate the anticipated thermal expansions);
- Vent pipes (f required).

Designs to install the casing through (or attached to) the bridge deck, abutments, piers and diaphragms must be approved by the owner of the bridge.

Conclusion

The concepts outlined in this paper will serve as the foundation for a reliable PE bridge crossing design. Many more site specific design considerations and construction issues will need to be addressed by the designer. Although PE pipe behaves differently than steel, a safe and economical bridge crossing design can easily be generated by a designer familiar with the properties of PE pipe and the mechanics of bridge construction.

Design Considerations for PE Bridge Crossings

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EXHIBIT D

BAY STATE GAS COMPANY
WAIVER APPLICATION

**See original for Plexco Bulletin No. 109

Table I Time and Temperature Elastic Modulus

PE 3408: Design Values for Apparent Modulus of Elasticity (in 10^3 psi)*

Duration	Temperature, °F							
	-20	0	40	60	73	100	120	140
Short Term	300.00	260.0	170.0	130.0	100.0	100.0	65.0	50.0
10 h	140.8	122.0	79.8	61.0	46.9	46.9	30.5	23.5
100 h	125.4	108.7	71.0	54.3	41.8	41.8	27.2	20.9
1000h	107.0	92.8	60.7	46.4	35.7	35.7	23.2	17.8
1 y	93.0	80.6	52.7	40.3	31.0	31.0	20.2	15.5
10 y	77.4	67.1	43.9	33.5	25.8	25.8	16.8	12.9
50 y	69.1	59.9	39.1	29.9	23.0	23.0	15.0	11.5

*Values derived from values published by PPI in "Above Ground Applications for Polyethylene Pipe," Table 8.1, and are considered to be industry accepted values for design use.