Calculating and Accommodating Thermal Movement in Piping Systems

All materials experience dimensional growth as a result of a change in temperature of the actual material. Piping systems can see both expansion and contraction growth due to changes in ambient temperature as well as the temperature differentials occurring between the piping system, installation, and operating temperatures. Expansion and contraction of the piping system can cause damage if not accounted for during the design of the system. This report covers considerations for accommodating thermal expansion and contraction of piping systems utilizing Victaulic products. Pipe movement due to other causes (e.g.: seismic, settlement, etc.) must be taken into consideration in addition to pipeline thermal movement.

Piping systems subjected to temperature changes could be placed in a condition of stress, exerting potentially damaging reactive forces and/or moments on components or equipment. These stresses can be reduced or eliminated by utilizing Victaulic products and various piping design methods. There are four methods using Victaulic products to accommodate pipe movement due to temperature differentials or changes.

1) Utilizing the linear movement capabilities of individual Victaulic flexible couplings. Note that linear movement is along the axis of the pipe.

2) Utilizing the linear movement capabilities of a Victaulic inline expansion joint.

3) Utilizing the angular deflection capabilities of Victaulic flexible couplings on Victaulic flexible expansion loops.

4) Utilizing the angular deflection capabilities of Victaulic flexible couplings at system offsets and changes in direction.

The selection of any of these design methods is dependent on the piping system layout, piping system design requirements, piping material, pipe diameter, and the designer's preference. Many piping systems often require the use of more than one method of thermal growth accommodation. Since it is impossible to predict all piping system layouts and designs, the intent of this paper is to call attention to the advantages of the grooved piping method and how it can be used to the piping system designer's benefit. The examples presented in this paper are used to present the various design methods combined with the use of Victaulic flexible products. These examples are presented to stimulate thought and should not be considered as recommendations for a specific piping system design.

Calculating Thermal Growth

The first step in accommodating thermal growth is to compute the exact change in the linear length of the piping system over the section of interest. The equation for calculating thermal expansion or contraction is shown below:

$$\Delta L = L \cdot \alpha \cdot \Delta T$$

ΔL = the change in linear length of the straight pipe section from the original pipe length.

L = original length of the straight pipe section.

α = the thermal coefficient of expansion for the specific pipe material.

ΔT = The change in material temperature of the piping system (This is usually the difference between the ambient temperature at time of installation and the minimum and/or maximum system operating temperature)

The thermal coefficient of expansion is specific to piping material. The thermal coefficients of expansion for commonly used pipe materials are shown in Table 1.

Pipe Material	In/ft °F	mm/m °C
Carbon Steel	8.0×10^{-5}	12.1×10^{-3}
Stainless Steel	11.5×10^{-5}	17.3×10^{-3}
Copper	11.2×10^{-5}	16.7×10^{-3}
PVC	34.8×10^{-5}	52.2×10^{-3}
CPVC	44.4×10^{-5}	66.7×10^{-3}

Table 1

Expansion coefficients may vary when obtained from different sources. This variability should be considered when making this calculation. Additionally, a suitable safety factor determined by the system designer should be applied to account for any errors in predicting operating extremes, etc.

An example illustrating the use of Table 1 follows:

ALWAYS REFER TO ANY NOTIFICATIONS AT THE END OF THIS DOCUMENT REGARDING PRODUCT INSTALLATION, MAINTENANCE OR SUPPORT.

Example:

240-foot long carbon steel pipe length.

Maximum operating temperature = 220°F (104°C)
Minimum operating temperature = 40°F (4°C)
Installation Temperature = 80°F (26°C)

Example Expansion Calculation:

Using Table 1, carbon steel pipe coefficient of expansion is
8.0E^{-5} in/ft°F, ΔT is 220°F (104°C) – 80°F (26°C) = 140°F (60°C), L = 240'. Applying Equation 1:

$$\Delta L = (240ft) \cdot (8.0E^{-5}\, in/ft°F) \cdot (140°F)$$

$$\Delta L = 2.69in/68.33mm$$

Example Contraction Calculation:

Using Table 1, carbon steel pipe coefficient of expansion is
8.0E^{-5} in/ft°F, ΔT is 80°F (26°C) – 40°F (4°C) = 40°F (4.5°C), L = 240'. Applying Equation 1:

$$\Delta L = (240ft) \cdot (8.0E^{-5}\, in/ft°F) \cdot (40°F)$$

$$\Delta L = .77in/19.56mm$$

Therefore, the pipeline will expand 2.69" (68.33mm) at its maximum operating temperature, and contract 0.77" (19.56mm) at its minimum operating temperature.

ACCOMMODATING THERMAL PIPE GROWTH

Victaulic methods for accommodating piping thermal movement (i.e. expansion and contraction) offer economical and efficient solutions. The following sections provide product information and suggestions which show the mechanical advantages of the Victaulic grooved piping method.

Introduction to Victaulic Flexible Couplings

When designing piping systems joined with Victaulic flexible couplings it is necessary to consider certain specific characteristics of these couplings. When understood, the piping system designer can utilize these characteristics to their advantage in the design of the actual piping system. Victaulic flexible couplings offer both linear and angular deflection movement capabilities. It is important to note that the flexible couplings full linear movement and full angular deflection cannot be achieved at the same time. If both movements are required, the piping system should be designed with sufficient joints to accommodate this requirement. Hanger positions shall be considered in relation to the angular and rotational movement that will occur at joints. Recommended hanger spacings are shown in the

Victaulic I-100 Field Installation Handbook and in the Design Data Section 26.01. Proper pipe anchoring and guiding shall also be considered when adding Victaulic flexible couplings to systems for thermal movement accommodation. This will be reviewed in the methods below.

1. **Utilizing the Linear Movement Capabilities of Individual Victaulic Flexible Couplings**

This section will explain how to accommodate for linear movement with Victaulic flexible couplings. Linear movement capabilities available at each flexible pipe joint is published under performance data for the specific Victaulic flexible coupling utilized. Victaulic flexible couplings allow for a small gap to be present between the two pipe ends inside the joint. This gap must be properly set when installing the Victaulic flexible couplings. For hot fluid systems, the piping is going to expand in length. In this case the joint should be installed with the maximum allowable pipe end gap to provide room for the pipe ends to expand into. For cold fluid systems, the piping is going to contract in length. In this case the joint should be installed with the minimum allowable pipe end gap to provide room for the pipe ends to contract into. For piping systems which experience both piping expansion and contraction, the pipe ends should be gapped accordingly between both of the above-mentioned gap limits. See the figure below for details of pipe end gapping within a flexible coupling joint.

Pipe ends
butted against
gasket

Pipe ends at full
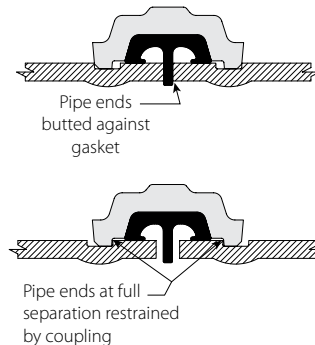separation restrained
by coupling

Figure 1

When accommodating for linear movement with Victaulic flexible couplings, consideration shall be given to pressure thrust loadings. The run of pipe shall be anchored at both ends to direct all movement within the couplings.

Proper pipe guiding shall also be taken into consideration when using Victaulic flexible couplings when accommodating linear movement. Pipe guides shall be placed on every other length of pipe joined by flexible couplings to prevent the piping from buckling and negatively impacting the couplings linear movement capability.

Sufficient flexible joints shall be installed to accommodate anticipated movement. An example calculation for linear accommodation with flexible couplings is provided below.

Example:

240-foot long carbon steel pipe

Maximum operating temperature = 220°F (104°C)

Minimum operating temperature = 40°F (4°C)
Installation Temperature = 80°F (26°C).

Earlier, the calculated thermal expansion for this piping system was 2.69" and the thermal contraction for this piping system was 0.77". The formula to calculate the required number of flexible coupling joints is:

$$\text{\# of Joints} = \Delta L / DVL$$

ΔL = Total Calculated Thermal Movement

DVL = Flexible Coupling Allowable Linear Movement Design Value

For this example, we will use the coupling data for a 4" Victaulic style 177N coupling. (Ref. Victaulic Submittal 06.24)

# of Joints for Expansion
= (2.69" + 0.77")/(0.18" per coupling)

# of Joints = 19.22 Couplings

Therefore, (20) 4" Victaulic style 177N couplings shall be required.

In this Example we can see that the calculated number of flexible joints to accommodate for the total linear pipe movement is 19.22. Since we can not provide a fraction of a coupling, this number should always be rounded up to the next highest round number. Given that, the total number of required flexible coupling joints to accommodate for the movement in this example is 20.

2. Utilizing the Linear Movement Capabilities of a Victaulic Inline Expansion Joint.

Victaulic offers multiple types of expansion joints. Expansion joints can accommodate larger amounts of movement in a smaller footprint when compared to using individual Victaulic flexible couplings at joints installed throughout a pipe run. Victaulic expansion joints are offered in a variety of pipe materials including carbon steel, galvanized steel, stainless steel, and CPVC. The amount of movement each expansion joint can accommodate will vary based on pipe size and pipe material. The Victaulic expansion joint product submittals should be referenced to find the amount of movement that a specific expansion joint can accommodate. Victaulic expansion joints do not require any maintenance and are designed for the lifespan of the piping system. These features are significant benefits when compared to traditional expansion joint products which require periodic maintenance.

As with all types of expansion joints, the designer shall guard against damaging conditions which these devices cannot accommodate, such as temperatures or pressures outside the product recommended range or motions which exceed the product's capability. For proper expansion joint operation, the piping system should be divided into separate expansion or contraction sections with suitable supports, guides and anchors to direct axial pipe movement. Anchors can be classified as main or intermediate for the purpose of force analysis. Main anchors are installed at terminal points, major branch connections, or changes of piping direction. The forces acting on a main anchor will be due to pressure thrust, velocity flow, and friction of alignment guides and weight support devices. Intermediate anchors are installed in long runs to divide them into smaller expanding sections to facilitate using less complex expansion joints. The force acting on the intermediate anchor is due to friction at guides, weight of supports or hangers, and the activation force required to compress or expand an expansion joint.

Proper guiding practices shall be used to prevent misalignment and buckling of the piping system to ensure that the expansion joint is only subjected to linear movement and not deflection. Additional intermediate guides may be required throughout the system for pipe alignment. If the expansion joint cannot be located adjacent to an anchor Guides shall be installed on both sides of the expansion joint. Proper guiding practices can be found in Victaulic submittal 09.06 or in the individual product submittal.

 In addition, where long length, low pressure applications may require few intermediate alignment guides, the pipe weight, including any liquid contents, must be adequately supported. Proper supporting for Victaulic expansion joints can be found in Victaulic

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submittal 09.06, or in the individual Victaulic product submittal. Figure 2 illustrates a typical application of expansion joints, anchors, and guides.
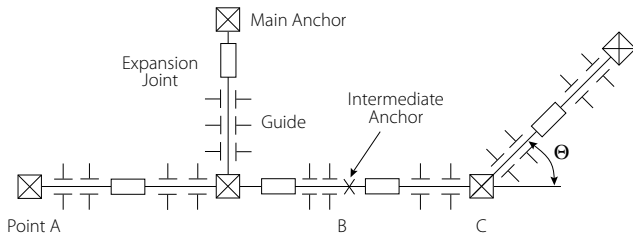

Figure 2

Expansion joints also cause additional reaction forces at anchors which must be considered in anchor design. This additional force is called activation force and is the amount of force that is required to make the expansion joint move. The activation forces required to compress or expand Victaulic expansion joints will be equivalent to 15 psi internal pressure multiplied by the cross sectional area.

Example:

Activation Force for 4" IPS Sized Pipe

$$F(a) = \frac{(\pi \cdot OD^2)}{4} \cdot 15 \text{ psi}$$

$$F(a) = \frac{(\pi \cdot 4.500"^2)}{4} \cdot 15 \text{ psi}$$

$$F(a) = 238.57 \text{ } Lbs$$

3. Utilizing the Angular Deflection Capabilities of Victaulic Flexible Couplings on Victaulic Flexible Expansion Loops

Victaulic offers the designer the advantage of using Victaulic flexible couplings in expansion loops thereby reducing or eliminating stresses in the piping system. The angular deflection capability of Victaulic flexible couplings allows for thermal expansion and/or contraction to be absorbed within the couplings at changes of direction within the piping system.

An example of this is illustrated below:
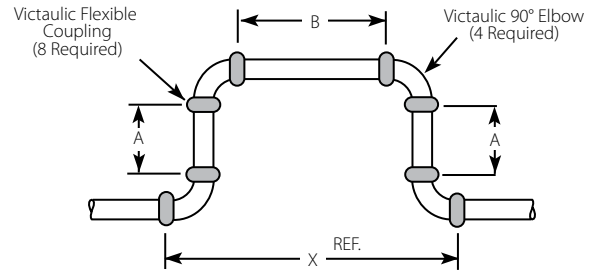
Figure A
Expansion Loop
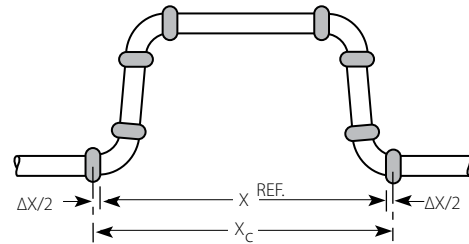
Figure B
Thermal Contraction
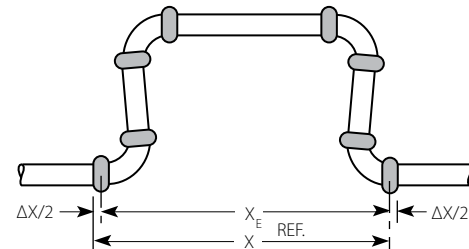Pipeline Shrinks – Loop Expands

Figure C
Thermal Expansion
Pipeline Grows into Loop – Loop Contracts

A total of eight (8) Victaulic flexible couplings, four (4) Victaulic grooved 90° elbows and three (3) pipe spools are required to complete each expansion loop as shown in Figure A. As the piping system temperature is reduced and the pipe runs contract (see Figure B), the loop expands, and the deflection capability of the couplings accommodate this movement. As the piping system temperature increases (see Figure C), the opposite behavior occurs. The pipe runs expand and the loop contracts with the couplings accommodating the deflection in the opposite direction.

The angular deflection available at each Victaulic flexible coupling is a design characteristic inherent to the coupling size and style. The length of the perpendicular branches of the loop (Dimension "A") is determined by the amount of expected pipeline expansion/ contraction (ΔL) and the combined deflection available from the Victaulic flexible couplings. The deflection of Victaulic flexible couplings in an expansion loop is dictated by how many pairs of couplings there are. Since there are eight (8) Victaulic flexible couplings on an expansion loop, there are four (4) pairs of couplings, thus the

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deflection capability of a Victaulic flexible coupling used on an expansion loop is multiplied by 4. Dimension "A" shall be the same on both sides of the expansion loop. The length of the parallel branch of the expansion loop (Dimension "B") is determined by ΔL, and it must be sufficiently long enough to prevent the lower elbows at the pipe run from butting during thermal expansion.

Consideration shall also be made for insulation thickness if applicable.

$$A = \Delta L / 4 \cdot DV_D$$

$$B_{min} = 2" + \Delta L + 2(\text{Insulation Thickness})$$

The nominal pipe size and either the design thermal expansion (ΔL) or the length of perpendicular branches (A) must be known before the parallel branch, Dimension "B", can be determined.

For an expansion loop to function properly it is essential that the piping system be properly anchored. Guiding requirements for the loop are to be determined by the system designer.

Example:

Using the parameters established in the previous section's example for accommodating thermal expansion; 4" (150 mm) nominal pipe size and 2.69" of total anticipated movement, we can calculate the size of the loop necessary to accommodate for the movement using the formula above.

For this example, we will use the coupling data for a 4" Victaulic Style 177N coupling. Ref. Victaulic Submittal 06.24. We will also use an insulation thickness of 2".

A = 2.69"/4·0.48" per foot

A = 1.40' (0.43m)

B= 2"+ 2.69" + 2 (2")

B = 8.69" or 0.71' (0.22m)

(Note: The Victaulic I-100 Field Installation Handbook should be referenced to determine the shortest allowable nipple length for grooving)

From the example we can see that in order to accommodate for 2.69" of movement, a loop utilizing 4" Victaulic Style 177N couplings needs to have a minimum (A) dimension of 1.40' and a minimum (B) dimension of 0.71'.

Expansion loops can also be used to accommodate for movement on copper tubing. Victaulic does not offer a flexible coupling for copper tubing, but an expansion loop can be made utilizing Victaulic rigid couplings for copper and sizing the loop as if it were hard piped.

The necessary length of a copper tube expansion loop can be calculated from the following formulas:

$$L = \sqrt{\frac{3\ EDe}{S}}$$

L = Loop length, in inches, as shown in the figure below

Victaulic 90° Elbow (4 Required)

Victaulic Coupling for Copper Tubing (8 Required)

2H + W = L
H = 2W
5W = L
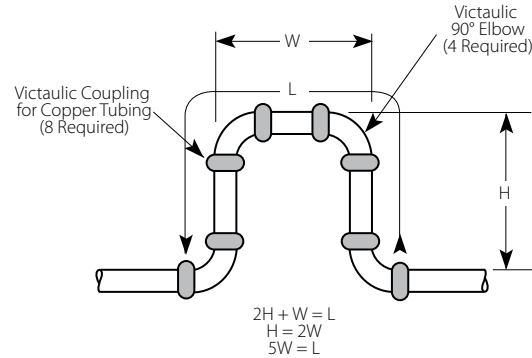
E = modulus of elasticity of copper in psi = 15,600,000 psi (107,546,400 kPa)

S = allowable stress of material in flexure, in psi = 6000 psi (41,364 kPa)

D = outside diameter of copper tubing in inches

e = amount of expansion to be absorbed, in inches

Simplifying the formula:

$$L = 88.32 \sqrt{De}$$

References:

(1) Copper/Brass/Bronze Product Handbook, Copper Development Association, Inc.

(2) Source book on Copper and Copper Alloys, American Society for Metals.

4. Utilizing the Angular Deflection Capabilities of Victaulic Flexible Couplings at System Offsets and Changes in Direction

Similar to expansions loops, the angular deflection capabilities of Victaulic flexible couplings can be used at system offsets and changes in direction to accommodate thermal expansion and contraction. While expansion loops sometimes require additional piping to be used in the system, typically this method uses system offsets and changes in direction that already exist within the piping systems design. By strategically placing pairs of Victaulic flexible couplings on elbows at system offsets and changes in direction, thermal expansion and contraction can be absorbed in a relatively small footprint. This method could also possibly reduce the number of anchors and guides needed in the system using dedicated expansion joint products. As with an expansion loops, couplings are utilized in pairs. The distance between a pair of couplings, the "Y" dimension, combined with the allowable deflection of a coupling dictates how much movement can be absorbed by the couplings at any one location. The longer the "Y" dimension is the more movement can be absorbed for a particular flexible coupling. The angle of the offset also plays a role in how much movement can be absorbed. The necessary "Y" dimension needed to accommodate a specific amount of movement can be calculated using the formula below.

$$Y = \Delta L/(DV_D)$$

X = Anchor
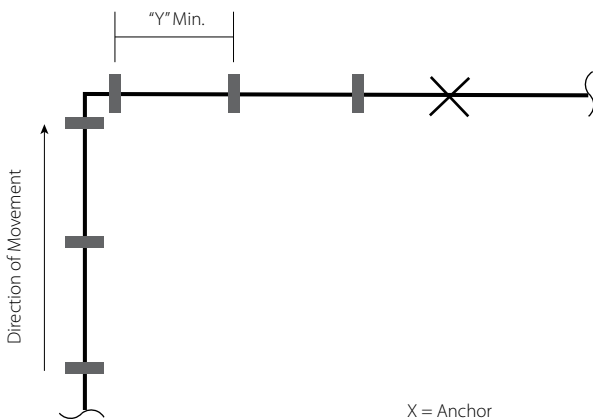
Where ΔL is the expected amount of thermal expansion or contraction, and DV_D is the available deflection for the coupling being used. This calculation is valid for system offsets that are perpendicular to the changing pipe and offers the maximum amount of movement. For system offsets and changes in direction that are not 90 degrees, the actual pipe angle must be taken into account. The formula for calculating the "Y" dimension with different angles can be seen below:

$$Y = (\Delta L/DV_D)/Sin(\Theta)$$

Θ = the angle of the offset

X = Anchor
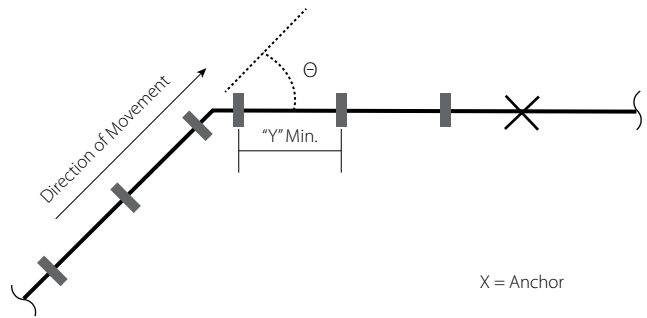
Below are example calculations for a 90 degree offset and a 45 degree offset.

Example:

Using the parameters established in the previous section's example 4" (100 mm) nominal pipe size and 2.69" of total anticipated movement we can calculate the necessary "Y" dimension needed to accommodate for the movement using the formulas above.

For this example, we will use the coupling data for a 4" Victaulic Style 177N coupling. Ref. Victaulic Submittal 06.24

For 90 Degree Offset
$$Y = \Delta L/(DV_D)$$
$$Y = 2.69"/0.48" \text{ Per Ft}$$
$$Y = 5.60' \text{ (1.71m)}$$

For 45 Degree Offset
$$Y = (\Delta L/DV_D)/Sin(\Theta)$$
$$Y = (2.69"/0.48" \text{ Per Ft})/Sin(45)$$
$$Y = 7.93' \text{ (2.42m)}$$

With the example we can see that a 90 degree offset would require a "Y" dimension of 5.60' to accommodate for the movement, but a 45 degree offset would require a "Y" dimension of 7.93' to accommodate for the same amount of thermal movement.

If there is not sufficient space in the piping system to place the correct length of pipe to accommodate the expected amount of movement additional pairs of Victaulic flexible couplings can be used. The total "Y" dimension calculated to accommodate the movement can be shortened by adding additional pairs of Victaulic flexible couplings. The available movement directly correlates to the number of pairs of couplings used at the offset. If two pairs of couplings are used, there is now twice as much deflection capability available, and therefore the total "Y" dimension to accommodate for the movement would be half the length needed for only 1 pair of couplings (two total couplings). The "Y" dimension can be shortened even more by continuing to add pairs of couplings until the desired dimension is

achieved. The formula to calculate the necessary "Y" dimension when using multiple pairs of couplings is below.

$$Y = \Delta L / X \cdot DV_D$$

X = # of pairs of couplings

Branch lines can also be subject to movement when the main piping system is expanding or contracting. If the branch line movement is not accommodated for, it is possible to damage the branch lines or any equipment that they may be connected to. The same method described in this section can also be applied to accommodate for movement at branch lines when branch line movement exists. Branch lines can be treated as a system offset/change in direction using the same formulas.

Direction of Movement

"Y" Min.
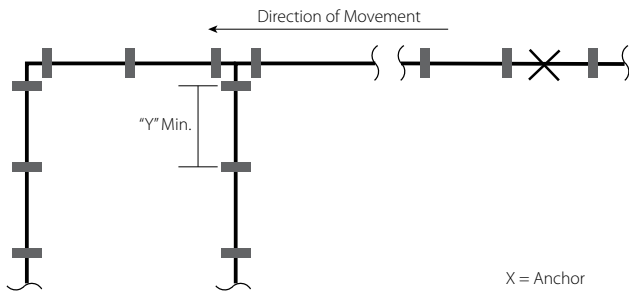
X = Anchor

One of the benefits of utilizing this method of thermal growth accommodation is that a minimum number of anchors is required to be installed in the system. When utilizing Victaulic flexible couplings at system offsets and changes in direction, anchors are typically only required in critical areas where movement is not wanted such as where horizontal piping systems connect to the riser piping in the building, or areas where the pipe is up against a wall or beam and cannot move. This method can also be utilized in "free floating" systems where there are no anchors installed and the pipe is able to grow/contract freely and the movement is accommodated by utilizing Victaulic flexible couplings at all system offsets and changes in direction.

Summary

Victaulic groove system products provide system designers with a variety of different methods to accommodate for thermal expansion and contraction within a piping system. A combination of these methods can be used to provide the optimal solution for thermal movement accommodation within a particular piping system. Please contact your local Victaulic representative for assistance with choosing the most applicable method for accommodating your specific pipeline thermal growth requirements.