

EXTREME TEMPERATURE PIPING APPLICATIONS

S9.1 – Introduction:

Piping for extreme temperature applications such as steam lines and cryogenic lines must be treated differently than normal HVAC or plumbing piping. This is due to the fact that the piping will change significantly in length between the as installed condition and the operating condition. The rules for seismically restraining pipe may need to be modified slightly when dealing with extreme temperature applications, as compared to those rules used for more normal applications.

S9.2 – Extreme Temperature Piping Run:

Extreme temperature piping designers want to closely control both the amount and the direction of expansion or contraction in each section of pipe between the installation and operating temperatures. Typically, a section of pipe is joined to adjacent sections through the use of expansion/contraction joints on either end, as shown in Figures S9-1 and S9-2 below. The length of the section of pipe between two expansion/contraction joints is designed to be within the range of travel that can be accommodated by the expansion/contraction joint.

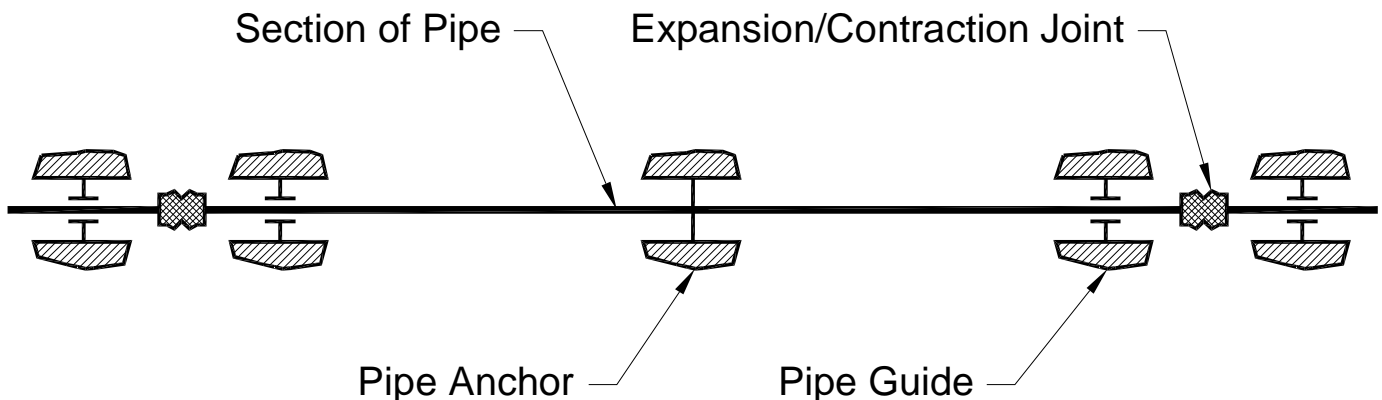


Figure S9-1; Typical Section of Extreme Temperature Piping – Center Anchor

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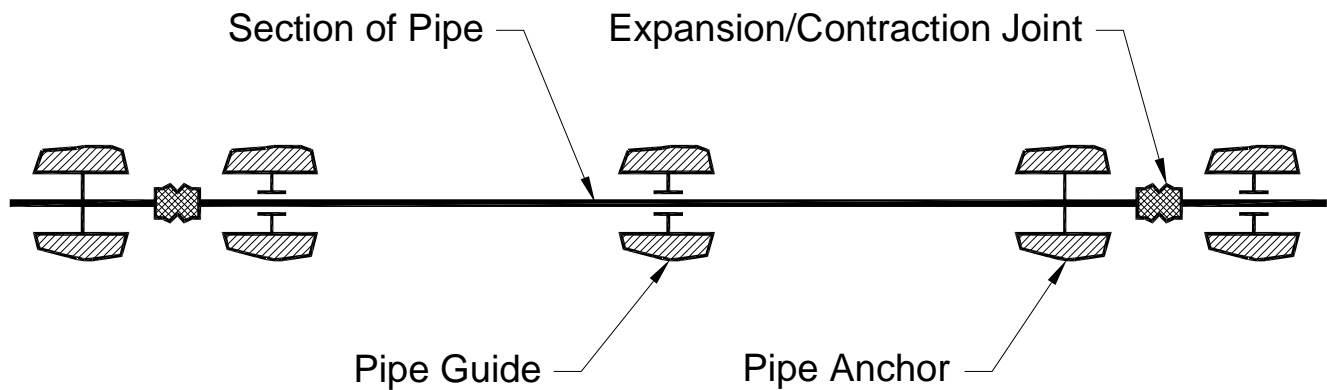


Figure 2; Typical Section of Extreme Temperature Piping – End Anchor

It is common practice, especially with steam lines, to anchor each section pipe to the building structure at one location. The normal anchor location is either in the center of the pipe section or at one end. When the anchor is in the center of the pipe run, the expansion or contraction is divided equally between the expansion/contraction joints on either end of the pipe section. When the anchor is located at one end, the expansion or contraction is taken up by the expansion/contraction joint at the opposite end of the pipe section. Along with an anchor, each section of pipe will require at least two guides that will support the dead weight of the pipe, and still allow the pipe to move with the thermal expansion and contraction.

Each section of pipe between expansion/contraction joints will behave independently from as compared to other interfacing sections when subjected to the earthquake motion. In order to provide adequate seismic restraint, the section of extreme temperature pipe that is located between two expansion/contraction joints will be treated as a full run of pipe. That is, the section of pipe between two expansion/contraction joints must have at least two transverse seismic restraints and at least one longitudinal restraint, per RULE #6 and RULE #8 from Section S1.0.

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S9.3 – Seismic Restraint Locations for Extreme Temperature Piping:

Many steam lines also carry steam at pressures greater than atmospheric, and thus are required to comply with the ASME code for pressure piping. ASCE/SEI 7-05 Section 13.6.8.1, which is a reference document for 2006 IBC, provides an important exemption for pressure piping systems, and is quoted directly below.

13.6.8.1 ASME Pressure Piping Systems. Pressure piping systems, including their supports, designed and constructed in accordance with ASME B31 shall be deemed to meet the force, displacement, and other requirements of this section. In lieu of specific force and displacement requirements provided in ASME B31, the force and displacement requirements of Sections 13.3.1 and 13.3.2 shall be used.

Thus, if documentation showing that the piping system was designed and constructed in accordance with ASME B31 exists, no further seismic restraint is required.

If the piping system was not a pressurized steam system and as such, was not required to be designed and constructed per ASME B31, then additional restraint will be required. For extreme temperature piping it is critical that the longitudinal seismic restraints be located as close to the anchor point as possible. In some cases, if adequately rated for seismic applications, anchors may be used as seismic restraints. This is because as thermal expansion or contraction of the pipe occurs, the further away from the anchor the longitudinal restraints are placed, the greater will be the amount of growth or shrinkage that the longitudinal restraint cables must accommodate. For either expansion or contraction, one restraint cable will become slacker, and the other one will become tighter than is expected in a normal pipe application. Because they are rigid, strut type seismic restraints are not recommended unless they are located immediately adjacent to an anchor. If the longitudinal restraints are located any distance away from the anchor, added tension or compression, driven by the thermal change in pipe length, will be induced in the restraints and can generate failures in either the restraint or the attachment to the pipe and the building.

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Figure S9-3 shows a case where the anchor is located in the center of the pipe section, and the length of the section is such that only one longitudinal restraint will be required. The longitudinal restraint is shown directly on top of the anchor, which is of course not possible. The restraint must be just to the right or left of the anchor. Note also that there are transverse restraints at the guide locations close to the expansion/contraction joints, and one with the longitudinal restraint. The transverse restraints are sized and located along the section of pipe as described in Sections S1.0 and S7.0, where S_T is the transverse restraint spacing. All of the restraints must be located close enough to pipe supports capable of resisting upward motion to counteract the upward reaction forces generated by the restraints. Sometimes the function of the guide is performed by roller supports for the pipe. If this is the case the supports at seismic restraint locations must be fitted with double rollers, on the top and bottom of the pipe, or a hoop strap over the pipe to keep the pipe from being disengaged from the roller by the seismic reaction forces, and to transfer these forces to the building structure.

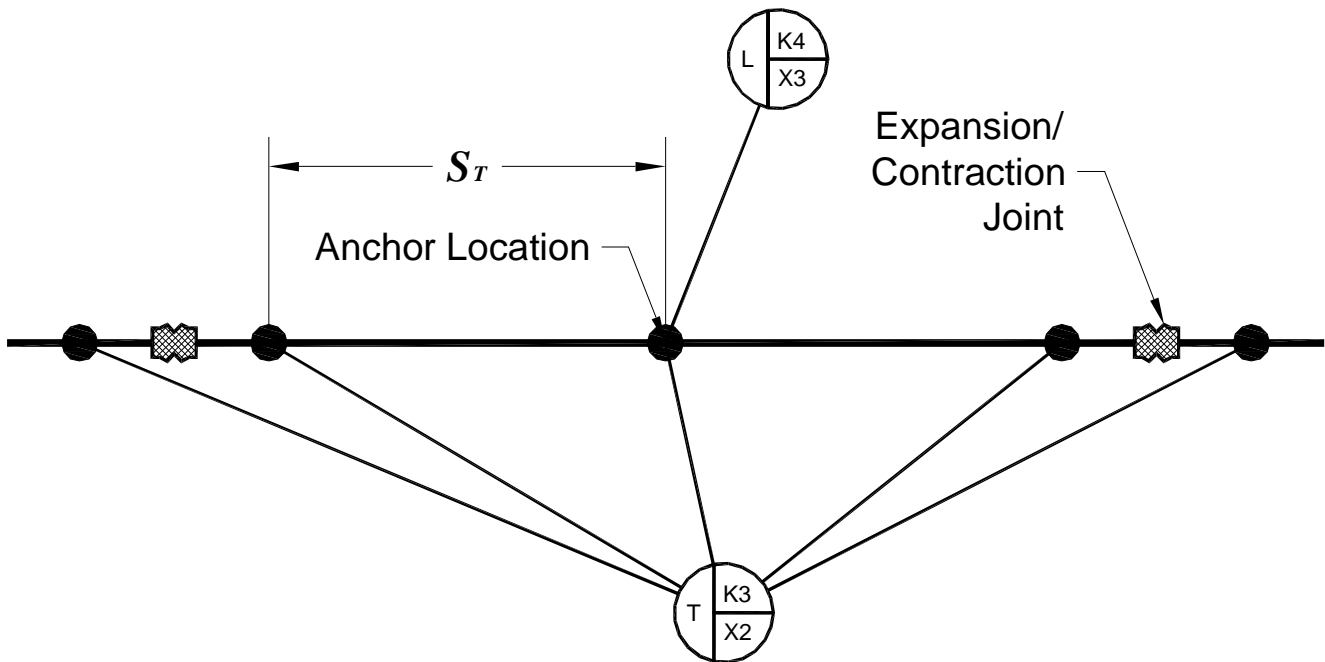


Figure S9-3; Seismic Restraints for Extreme Temperature Pipe with a Center Anchor and One Center Longitudinal Restraint

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Figure S9-4 shows a section of pipe with a central anchor whose length exceeds the maximum allowable spacing for the longitudinal restraints. In this case a longitudinal restraint is located on either side of the anchor. Each longitudinal restraint handles one half of the length of the pipe section between the expansion/contraction joints. If the section of pipe is longer than 160 ft, two longitudinal restraints may still be used provided that the following conditions are met.

1. The requirements for the restraint of the pipe may be met by the seismic restraint components and their anchorage hardware.
2. The compressive force in the pipe that is generated by the design seismic force is below the allowable buckling load of the pipe.

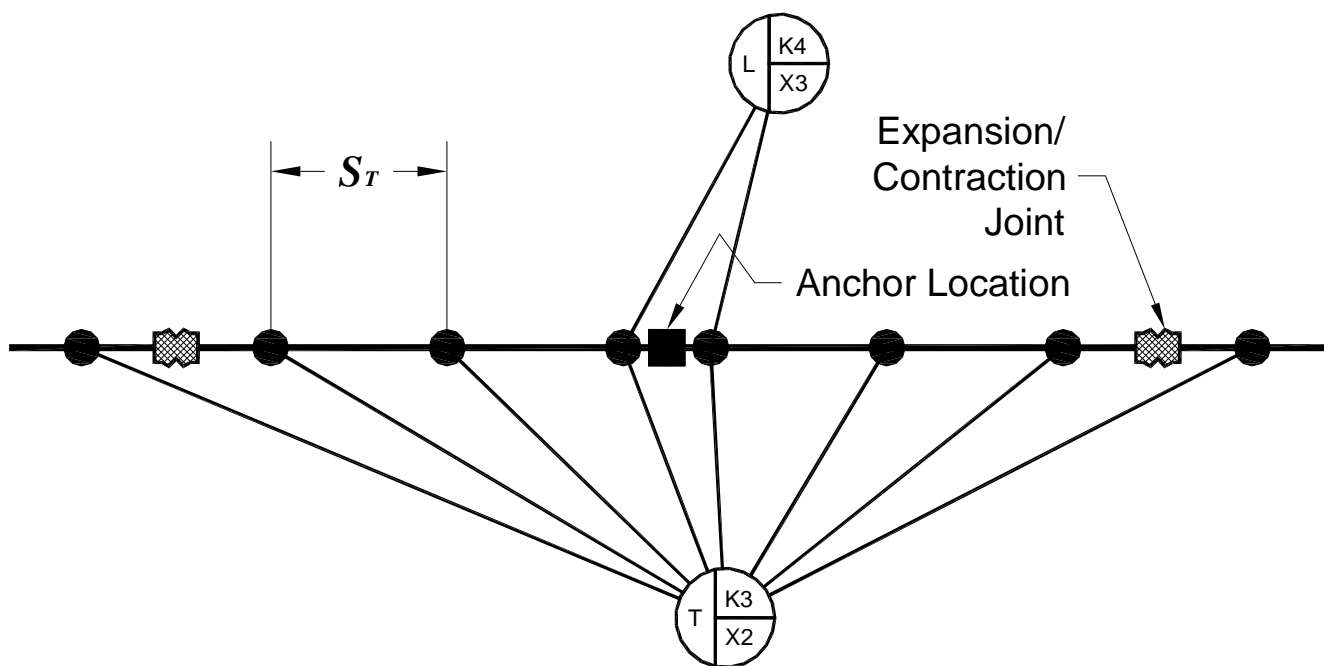


Figure S9-4; Seismic Restraints for Extreme Temperature Pipe with a Center Anchor and Two Center Longitudinal Restraints

Figure S9-5 and S9-6 show the seismic restraint schemes for the case where the section of pipe is anchored on one end. In each case the longitudinal restraint is shown at the anchor location. The actual attachment point to the pipe should be just to the left of the anchor. In both cases, the longitudinal restraints at the anchor must be capable of restraining the entire section of pipe. So,

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for a section of pipe with the anchor at one end, the section length can not exceed 80 ft to 100 ft. Thus, in order to use an end anchor scheme for the expansion/contraction control, the section lengths must be chosen with the seismic restraint requirements for the project in mind.

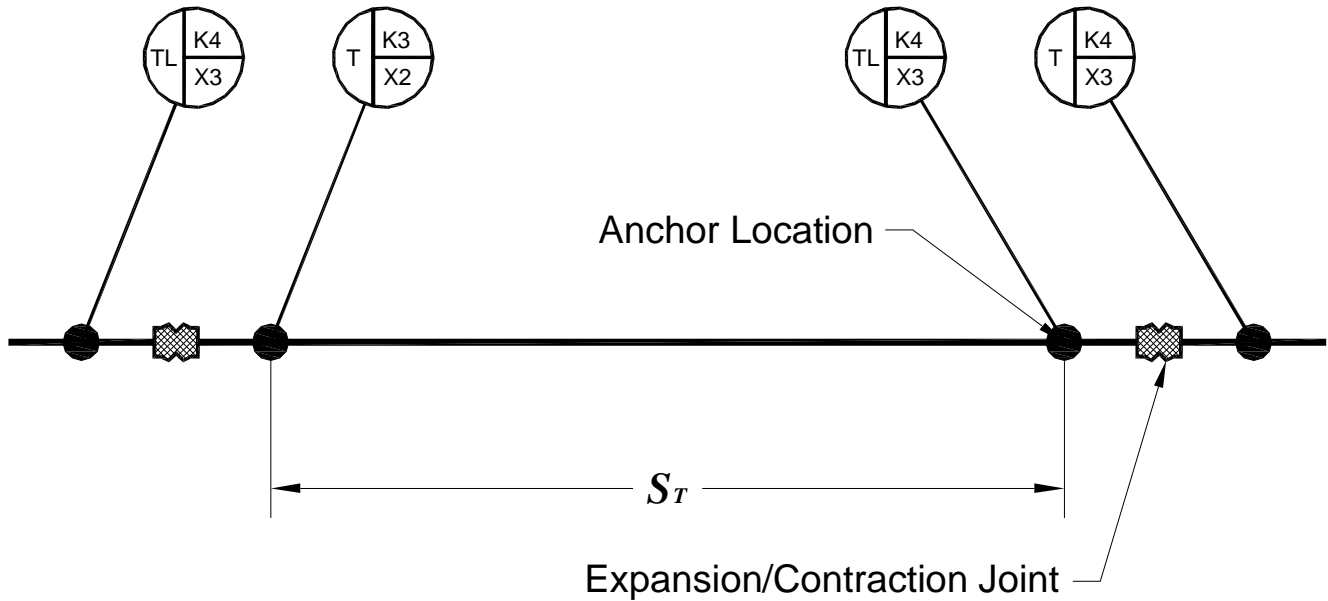


Figure S9-5; First Seismic Restraint Scheme for Extreme Temperature Pipe with One End Anchor

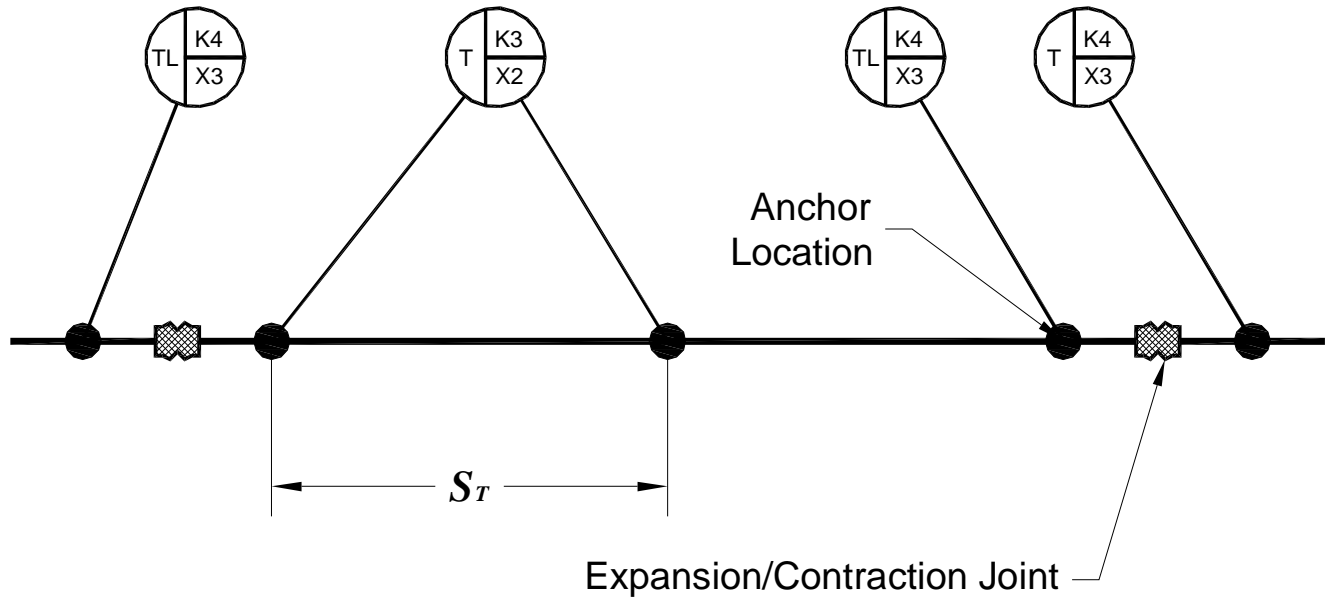


Figure S9-6; Second Seismic Restraint Scheme for Extreme Temperature Pipe with One End Anchor

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S9.4 – Seismic Restraints and Expansion Loops:

Expansion/Contraction joints are sometimes replaced by specially designed “dog-legs” in the pipe that are intended to absorb the expansion and contraction of the long horizontal runs of pipe. Such an expansion/contraction loop is shown in Figure S9-7. This loop would be designed to handle sections of pipe that were anchored in the center.

If the anchor was at one end of the pipe section, one of the guides in Figure S9-7 would be replaced by an anchor, and the anchor would be replaced by a guide as shown in Figure S9-8.

The seismic restraints for the expansion/contraction loop are shown in Figure S9-9. The adjacent to the pipe anchor at the center of the loop there will be both transverse and longitudinal restraints of sufficient capacity to restrain the weight of the entire three legs of the expansion/contraction loop. The ends of both sections of pipe supported with the pipe guides will have transverse seismic restraints located close to the pipe guides.

The seismic restraint scheme for the expansion/contraction loop for extreme temperature pipe with end anchors is shown in Figure S9-10. The guides will have transverse seismic restraints adjacent to them. The anchor at the end of the pipe section will have both transverse and longitudinal restraints adjacent to it. The longitudinal restraint must have enough capacity to restrain both the section of pipe and the expansion/contraction loop.

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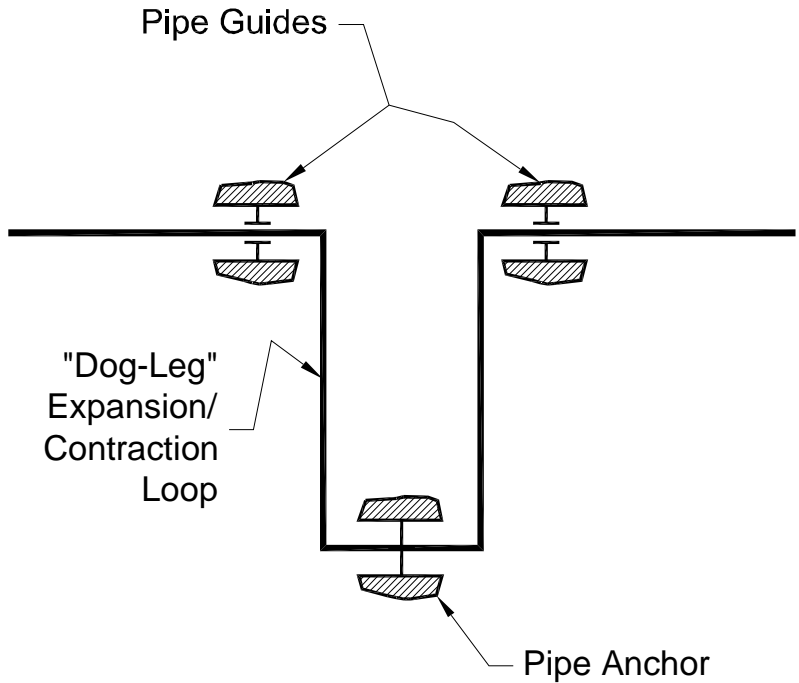


Figure S9-7; Expansion/Contraction Loop for Extreme Temperature Pipe with Center Anchors

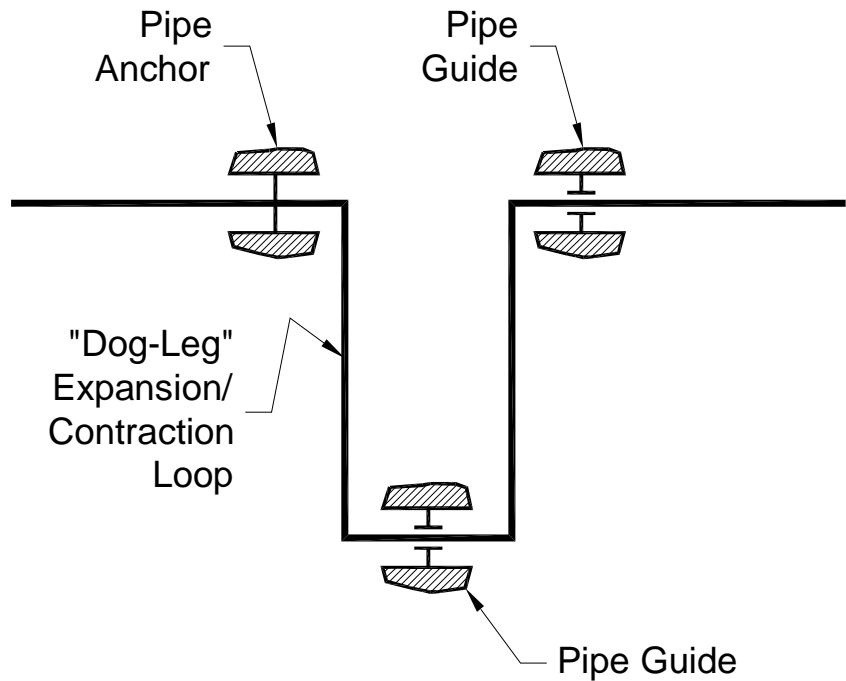


Figure S9-8; Expansion/Contraction Loop for Extreme Temperature Pipe with End Anchors

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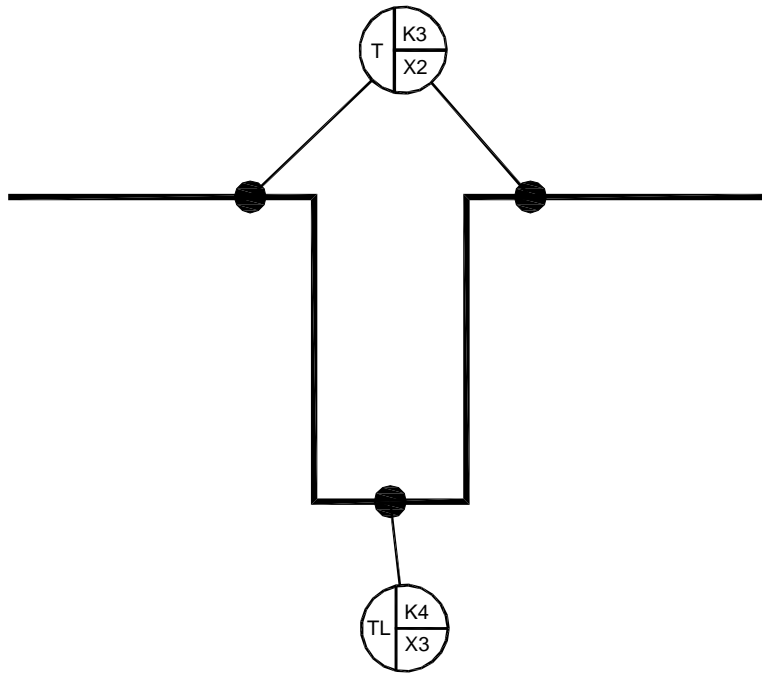


Figure S9-9; Seismic Restraints for Expansion/Contraction Loops for Extreme Temperature Pipe with Center Anchors

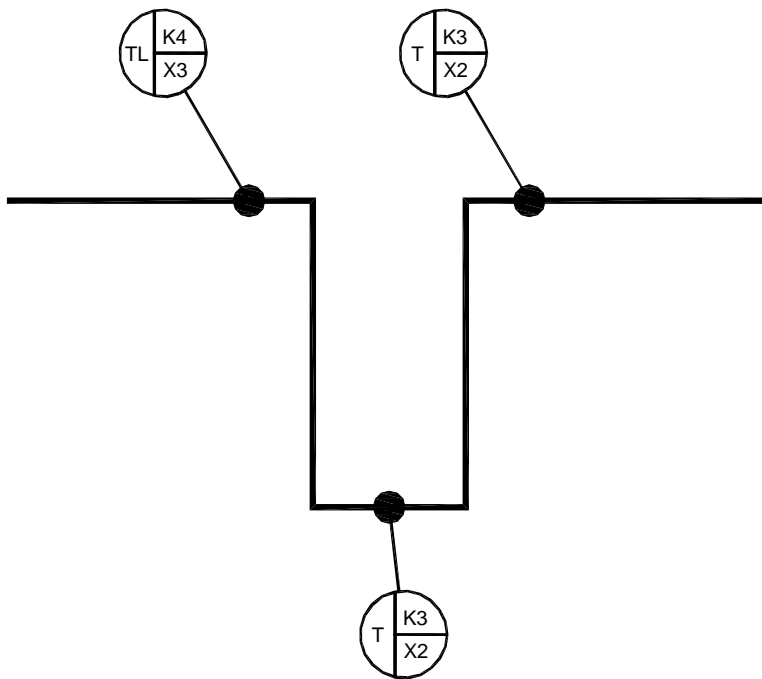


Figure S9-10; Seismic Restraints for Expansion/Contraction Loops for Extreme Temperature Pipe with End Anchors

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S9.5 – Non-Anchored Domestic Hot and Chilled Water Piping:

It is not unusual for domestic hot water piping systems to be designed and installed with no special provisions for anchoring the pipe, or controlling the expansion or contraction that may occur in normal operation of the system. In many cases the pipe sizes are rather small, but may not be small enough to fall under any of the code based exemptions. Whenever a longitudinal seismic restraint is introduced into a run of hot or chilled water piping, an anchor point is established and thermal growth or contraction will occur on either side of the longitudinal restraint location. Transverse seismic restraints that are placed “close” to corners will try to prevent the run of pipe in the other leg from growing or shrinking. This action may over stress the pipe and/or overload the transverse restraint cables that are closest to the corners.

For domestic hot or chilled water piping, the rules for applying longitudinal restraints must be as follows.

1. The longitudinal restraint must be located in the center of the piping run to allow the pipe to experience unrestrained axial growth or shrinkage at the ends of the run. Care must be taken that the restrained length of pipe on each side of the restraint is less than the amount that would cause buckling of the pipe under the expected design horizontal seismic force for the project, see Appendices A6.1, A6.2, and A6.3.
2. If the piping run is long enough that multiple longitudinal restraints are required, an expansion/contraction joint or expansion/contraction loop must be placed between the longitudinal restraints to accommodate the growth or shrinkage of the pipe.
3. When a run of hot or chilled water tees off of a main hot or chilled water line steps must be taken to ensure that the expansion or contraction of the main or the branch line does not place excessive stress on the other.

A typical layout for domestic hot and chilled water might appear as shown in Figure S9-11 below. Note that in the layout, the longitudinal seismic restraints are placed in the center of each run. The

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last transverse seismic restraints before each corner are placed a specific distance from the corner. This distance is specified in order to allow the pipe to growth or shrink in length along the two legs of the bend without exceeding the allowable stress in the pipe in bending.

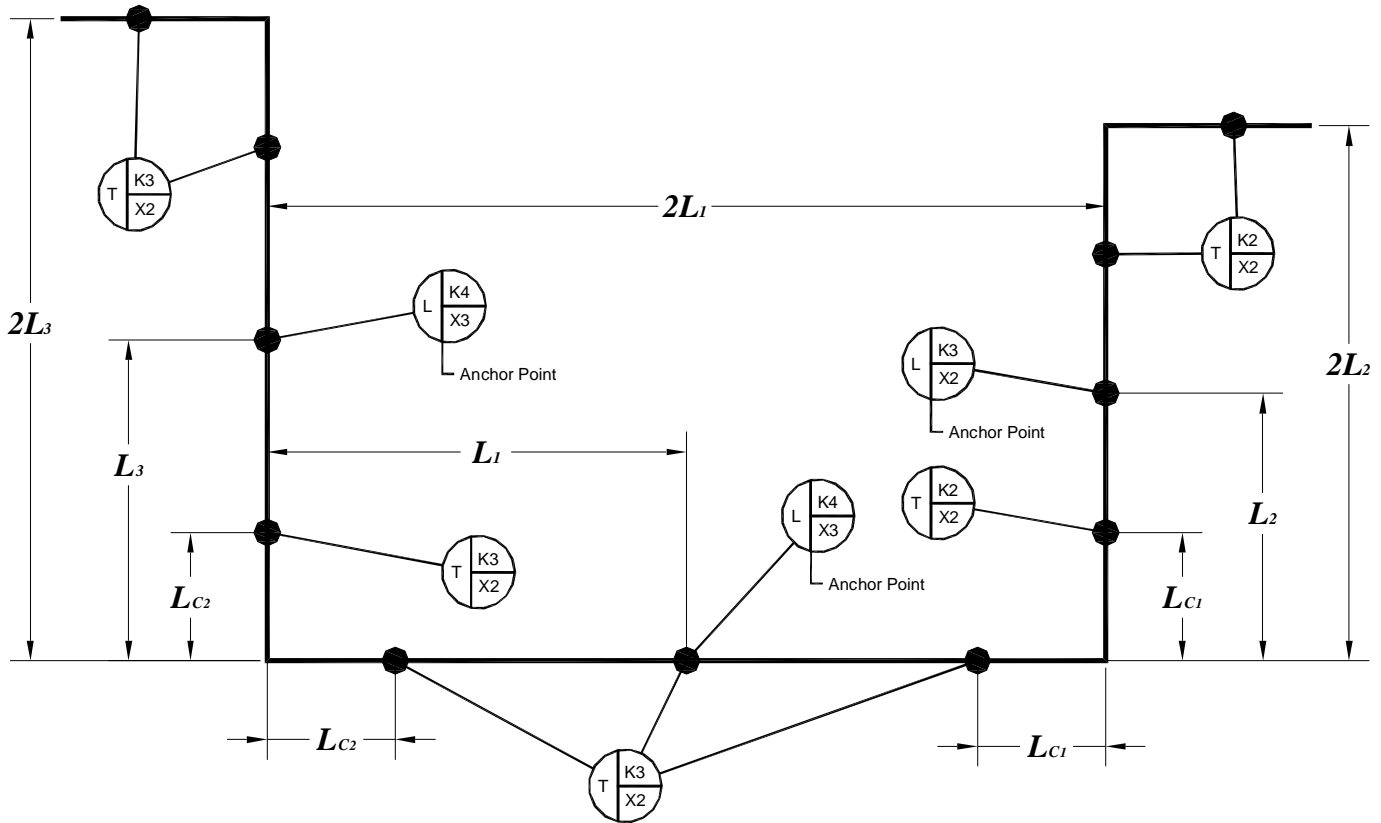


Figure S9-11; Typical Seismic Restraint Layout for Domestic Hot and Chilled Water

The distance from the corners to the first transverse seismic restraint will be determined by;

1. The pipe material.
2. The pipe size.
3. The distance from the longitudinal seismic restraint to the corner.
4. The difference between the installed temperature and the operating temperature of the pipe.

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This length from the corner to the first transverse seismic restraint may be estimated using equation (5) from the 2008 ASHRAE Handbook – HVAC Systems and Equipment; Chapter 45. This equation is repeated in a form that is more applicable to this application.

$$L_c = \sqrt{\frac{3\delta_p D_o E_p}{144S_A}}$$

Equation S9-1

Where:

L_c = the distance from the corner to the first transverse seismic restraint (ft.).

δ_p = the change in length, growth or shrinkage, due to the temperature difference between installation and operating conditions for the length of pipe from the longitudinal seismic restraint and the corner (in.).

D_o = the outside diameter of the pipe or tube (in.).

E_p = the modulus of elasticity for the pipe material (psi).

$E_p = 30 \times 10^6 \text{ psi}$ Carbon Steel Pipe

$E_p = 17 \times 10^6 \text{ psi}$ Drawn Copper Tubing

$E_p = 4.2 \times 10^5 \text{ psi}$ PVC Pipe

$E_p = 3.6 \times 10^6 \text{ psi}$ CPVC Pipe

S_A = the allowable stress for the pipe material (psi).

$S_A = 15,000 \text{ psi}$ Carbon Steel Pipe

$S_A = 9,000 \text{ psi}$ Drawn Copper Tube

$S_A = 4,000 \text{ psi}$ PVC 1120 and CPVC 4120 Pipe

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The change in length of the pipe from the longitudinal seismic restraint to the corner may be determined as follows;

$$\delta_p = 12\alpha_p L(\Delta T) \quad \text{Equation S9-2}$$

Where:

α_p = the linear coefficient of thermal expansion for the pipe (in./in.°F).

$$\alpha_p = 6.31 \times 10^{-6} \text{ in./in.}^\circ\text{F} \text{ Steel Carbon Pipe}$$

$$\alpha_p = 9.5 \times 10^{-6} \text{ in./in.}^\circ\text{F} \text{ Drawn Copper Tubing}$$

$$\alpha_p = 30.0 \times 10^{-6} \text{ in./in.}^\circ\text{F} \text{ PVC 1120 Pipe}$$

$$\alpha_p = 35.0 \times 10^{-6} \text{ in./in.}^\circ\text{F} \text{ CPVC 4120 Pipe}$$

L = the distance from the longitudinal seismic restraint to the corner (ft.)

ΔT = the temperature difference between the installed condition of the pipe and the operating condition of the pipe (°F). This will be positive (+) for domestic hot water pipe and negative (-) for domestic chilled water pipe. Assuming an installation temperature of 60° F, a maximum temperature of 140° F for Domestic hot water, and a minimum temperature of 40° F for domestic chilled water the average temperature differentials may be taken as;

$$\Delta T = 80^\circ\text{F} \text{ Domestic Hot Water (Pipe Length Grows)}$$

$$\Delta T = 20^\circ\text{F} \text{ Domestic Chilled Water (Pipe Length Shrinks)}$$

Substitution of Equation S9-2 into Equation S9-1 will yield the following result.

$$L_c = 0.5 \sqrt{\frac{\alpha_p L \Delta T D_o E_p}{S_A}} \quad \text{Equation S9-3}$$

For Standard Steel Pipe:

$$L_c = 0.502 \sqrt{L D_o} \text{ Domestic Hot Water} \quad \text{Equation S9-4}$$

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$$L_c = -0.251\sqrt{LD_o} \text{ Domestic Chilled Water}$$

Equation S9-5

For Drawn Copper Tubing:

$$L_c = 0.599\sqrt{LD_o} \text{ Domestic Hot Water}$$

Equation S9-6

$$L_c = -0.300\sqrt{LD_o} \text{ Domestic Chilled Water}$$

Equation S9-7

For PVC 1120 & CPVC 4120 Pipe:

$$L_c = 0.251\sqrt{LD_o} \text{ Domestic Hot Water}$$

Equation S9-8

$$L_c = -0.125\sqrt{LD_o} \text{ Domestic Chilled Water}$$

Equation S9-9

For any particular corner, the value of L_c that is used should be based on the leg with the longest distance from the longitudinal restraint to the corner in question. For instance, referring to Figure S9-11, the value for L_{c1} will be based on L_1 or L_2 whichever is larger, and L_{c2} will be based on the larger of L_1 and L_3 . Values for L_c are shown in the tables or Appendix A2.6 for hot or chilled domestic water lines for various pipe sizes and materials. These tables are rather extensive and can be used for special design situations. However, the values in Table S9-1 will be suitable for most applications.

Table S9-1; Basic Corner Distance for Domestic Hot & Cold Water Piping to First Transverse Seismic Restraint for Distances from the Corner to the Longitudinal Restraint Up to and Including 40 ft and Temperature Differences Up to and Including 80° F.

Applicable Pipe/Tubing Size Range (in)	Distance From Corner To Transverse Seismic Restraint L_c (ft)
3/4 to 2-1/2	5
3 to 10	10
11 to 22	15

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S9.6 – Trapeze Supported Extreme Temperature Piping:

There may be occasions when steam line, a chilled water line, or a domestic hot water line will be supported by trapeze bars along with other piping that does not need to meet the seismic restraint requirements for extreme temperature piping, see Figures S9-12 and S9-13 below. Special considerations must be taken into account when restraining the trapeze supported piping where one or more of the supported lines will experience expansion or contraction.

1. When large diameter pipes are being used which have large changes in pipe length due to expansion or contraction for a particular run of pipe, the use of expansion/contraction joints is recommended. This will require the use of pipe anchors and guides as described in Sections S9.2 and S9.3. The trapeze bars and their supports will need to be designed to handle all of the dead loads and thermal loads.
2. When anchors and guides are not used, as in domestic hot water lines and some chilled water lines, the lines must be anchored in one location as discussed in Section S9.5.
 - a. The longitudinal seismic restraint that is being used as the anchor may be attached either to the trapeze bar directly or to the pipe.
 - i. If the longitudinal seismic restraint is attached to the trapeze bar, Case-1 Figure S9-12, the hot or chilled water pipe must be **tightly clamped** to the trapeze bar, and the restraints sized to handle the seismic forces generated by all of the pipes being supported by the trapeze bar.
 - ii. If the longitudinal seismic restraint for the hot or chilled water pipe is to be attached, clamped, directly to the hot or chilled water pipe, Case-2 Figure S9-13, it must be located within $\pm 4"$ of the trapeze bar, and uplift control must be provided for the pipe at the trapeze bar to transfer the vertical seismic reactions to the trapeze bar hanger rods. See Sections I3.0 and I6.0 for uplift control schemes for extreme temperature piping.
 - iii. When a run of hot or chilled water tees off of a main line that is trapeze supported with other pipes, steps must be taken to ensure that the expansion or

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contraction of either the main or the branch line does not excessively stress the other line, or twist the trapeze bar(s) to bend the hanger rods.

- b. The hot or chilled water lines must be allowed to expand or contract freely on either side of the longitudinal seismic restraint that serves as the anchor point.
 - i. Care must be used to prevent interference at bends with the other pipes being supported by the trapeze bars when the hot or chilled water lines expand or contract.
 - ii. Where transverse seismic restraints are located on the hot or chilled water lines, transverse and vertical, uplift control, motion of the pipe must be limited. See Section I6.0 for examples of schemes for limiting transverse and vertical motion while allowing free expansion and contraction of the pipe.
 - iii. Rollers or slides may be used to support hot or chilled water lines that experience large amounts of motion, or frequent temperature cycles.

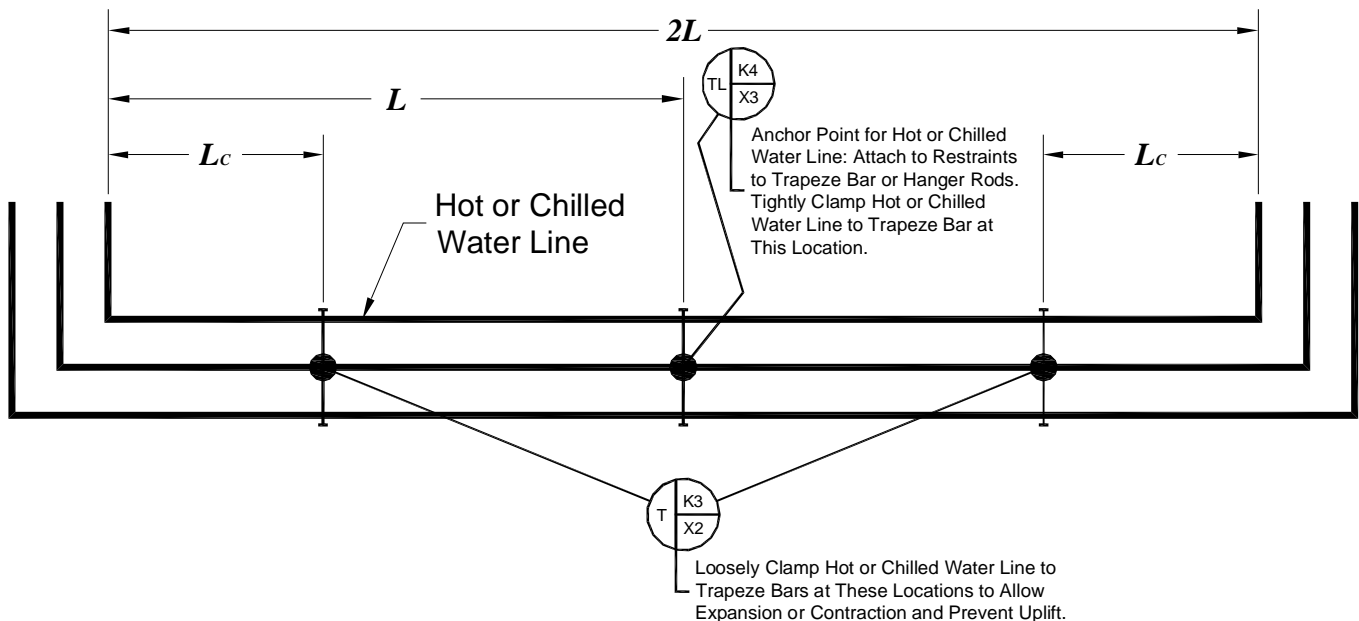


Figure S9-12; Hot or Chilled Water Line Trapeze Supported with Standard Water Lines: Case-1

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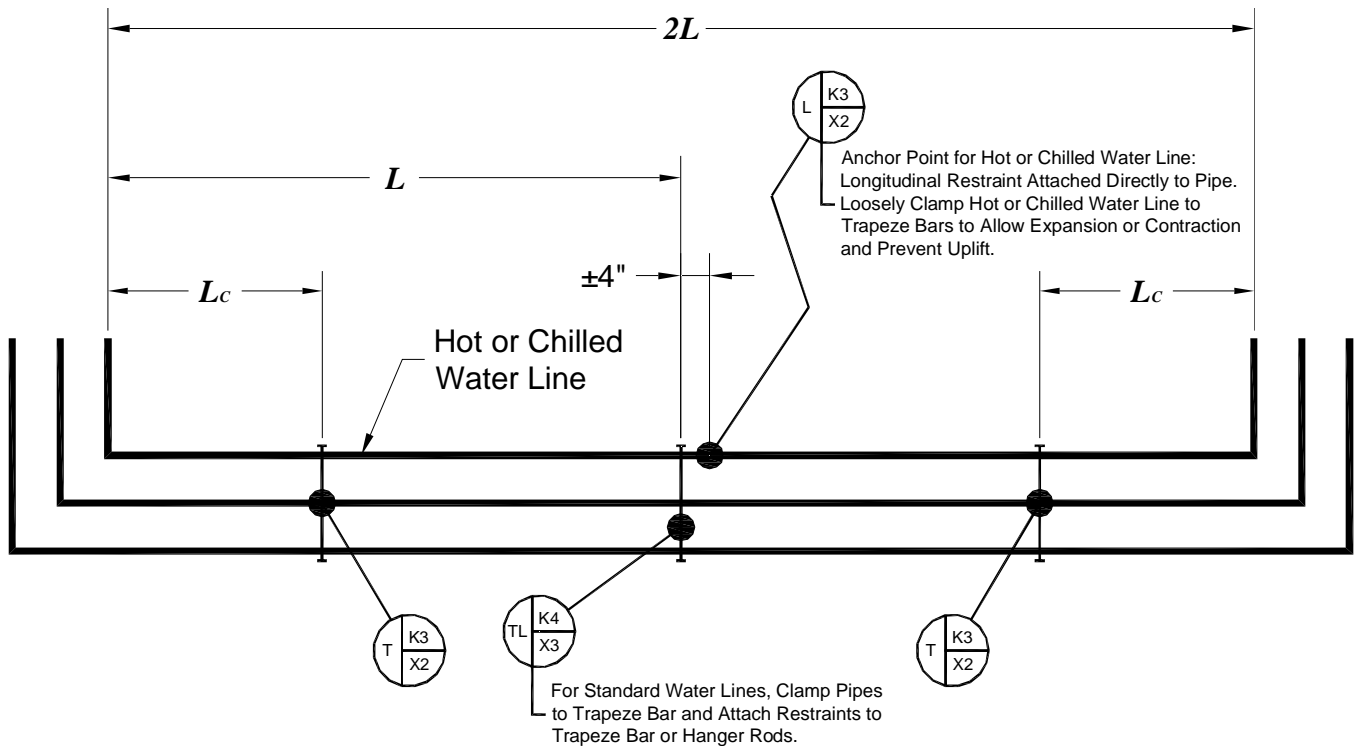


Figure S9-13; Hot or Chilled Water Line Trapeze Supported with Standard Water Lines: Case-2

S9.7 – Additional Transverse Seismic Restraints for Extreme Temperature Piping:

For extreme temperature piping, the run of pipe will have an anchor point either in the middle or at one end as described in the sections above, see figures S9-1 and S9-2. The longitudinal seismic restraint(s) for the run of pipe will be placed at the anchor point, see Figures S9-3 through S9-6. In the case of the domestic hot and chilled water, the longitudinal restraint(s) will be the anchor, see Figure S9-11.

Transverse seismic restraints are typically placed at the anchor point and at the “free” end of the run of pipe where the expansion and contraction are allowed to occur. Additional transverse seismic restraints may be required between the anchor point and the “free” end to prevent buckling of the pipe due to longitudinal seismic forces in the pipe. The proper number or transverse seismic restraints should be selected based on the length of the pipe between the anchor point and the “free” end, and minimum allowable restraint spacing values for the

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appropriate type of pipe as described in Section 8.0 in the tables in Appendices A6.1, A6.4, and A6.5.

S9.8 – Final Comments on Transverse Seismic Restraints for Extreme Temperature Piping:

The transverse seismic restraints will also be affected by the thermal expansion and contraction of the pipe. However, the effects will be to a much smaller degree than those experienced by the longitudinal restraints. Further, the cable type restraints are far less sensitive to the axial motion of the pipe than the strut type restraints. This is due to the geometry of the restraints. The change in length of the restraint for a given change in pipe length is relatively small, and may be compensated for in many cases by larger loops at the ends of the restraint cables, or slotted holes in the brackets used to attach the restraints to the pipe and structure. However, for piping systems that experience very large thermal displacements, the transverse restraints must be mounted to the pipe in such a way to accommodate the change in length of the pipe due to the temperature effects. Slider type clevis hangers or roller type clevis hangers are typically used to accommodate larger axial motion. The transverse seismic restraints can be attached to these types of hangers as long as some means, such as a top strap or upper roller, is used to transfer the vertical seismic reaction forces to the hanger.

In Section S1.0, RULE #9, it was stated that if transverse restraints were located within 24 inches, 2 feet, of a corner, that the transverse restraint on one leg could act as the longitudinal restraint on the other leg. This rule ***must not*** be globally applied to extreme temperature piping! Those transverse restraints which are located that close to the corner of an extreme piping run will be subjected to very large displacements which could fail the restraints or their anchorage. The last transverse restraints before the corner must be placed far enough away from the corner that they may grow or shrink as it will without overloading the restraints. This distance from the corner to the first transverse seismic restraints may be estimated using Appendix A2.6, Equation S9-3, or Equations S9-4 through S9-8.

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Dublin, Ohio, USA • Mississauga, Ontario, Canada

Toll Free (USA Only): 800-959-1229
International: 614-889-0480
FAX: 614-889-0540
World Wide Web: www.kineticsnoise.com
E-mail: sales@kineticsnoise.com

SECTION – S9.0

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