Managing Pipe Expansion in Shafts

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Designing to accommodate expansion is necessary for all piping systems, but it is even more critical in shafts because space is limited, and pipes are often constrained by taps out of the shafts. When the pipe in *Photo 1* and *Figure 1* expands vertically, the taps on each floor may be sheared off, causing water damage, especially if the shaft walls are very rigid (concrete or concrete block). Fire code violations are also possible because the pipes move off the center of the listed firestop system that is being used, potentially violating the listing of that system. This column discusses ways your designs can mitigate these risks.

Fundamentals of Pipe Expansion

Pipe materials differ in their coefficients of thermal expansion and their strength (*Table 1*). A common rule of thumb that is easy to remember is that steel expands 0.76 in. per 100 ft per 100°F (10.8×10^{-6} per °C). For a shaft 200 ft (61 m) tall with the pipe installed at 40°F (4.4°C) that has a maximum heating water temperature of 180°F (82.2°C), the total expansion is 2.1 in. (53 mm) (*Equation 1*).

$$(180°\text{F} - 40°\text{F}) \times 200\text{ ft} \times \frac{0.76\text{ in.}}{100°\text{F} \times 100\text{ ft}} = 2.1\text{ in.} \qquad (1)$$

This is plenty of expansion in many situations to shear off a pipe. We are aware of one project where this caused a break and water damage, which resulted in a claim by the building owner against both the engineer and the contractor.

In cold climates, buildings are often at least heated above freezing before pipes are installed, so 40°F (4.4°C) is often assumed as a worst-case assumption. A higher temperature may be appropriate in warmer climates. Also, if you use lower maximum temperatures to take advantage of condensing boilers or heat recovery chillers, you will reduce the amount of expansion and reduce your expansion problems.

Four scenarios can happen when a pipe expands:

1. The pipe can grow in length with either or both ends free to move. This is normally not a problem and is usually the most economical way to deal with expansion when possible.

2. The pipe expansion may be absorbed by flexible couplings, expansion joints or other items included in the design.

3. The pipe can grow in length with the ends restrained and “snake” or “bow,” which may lead to buckling. One author remembers a project in which the supply pipe inside finned tube baseboard heaters bowed

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and popped the covers off (*Photo 2*).

4. Sufficient guidance of the pipe by alignment guides and rigid anchoring at both ends prevents snaking or bowing, i.e., the pipe compresses. This can be an effective strategy for materials with low strength (mostly plastics), but with steel pipes the forces are usually much too high, and the anchors break. One of the authors vividly remembers a steam tunnel in which 12, ¾ in. (19 mm) bolts were sheared off, and the anchor had moved 6 in. (152 mm) down the tunnel.

We do not recommend designs that rely only on scenarios three and four.

A good example of Scenario 1 is a steam pipe that goes from a basement to a penthouse (*Figure 2*) and is left free to "float" at the bottom of the shaft. In this case we normally hang the pipes from the top and use spring hangers (the same type used for vibration control) near the riser at the bottom. Capacities of threaded rods are in the *2016 ASHRAE Handbook—HVAC Systems and Equipment*, Chapter 46, Table 9; however, the capacity of the anchor or upper support is often the limiting factor.

This method avoids the need for alignment guides (*Photo 3*) or any intermediate supports. It does require a strong hanger at the top, so you may want to calculate the maximum load on the upper hanger and note that on the plans. For plastic pipes filled with water, always check with the supplier about whether the joints are rated not to separate under this much weight.

This strategy can also work in reverse. We designed a chilled water plant with large steel condenser pipes going up ~12 stories to existing cooling towers. We anchored it with a welded angle ring at the base and installed alignment guides up the side of the building.

If the pipe is constrained as in Scenario 2 above, we now look at ways to accommodate this. There are several options.

The first option is offsets to reduce stresses in the pipe to acceptable levels. These are often L-bends (*Figure 3*), Z-bends (*Figure 4*) or U-bends. Their design is described in the *2016 ASHRAE Handbook—HVAC*

PHOTO 1 Riser expansion affecting fire rating. Note that pipe is off-center and appears deflected.

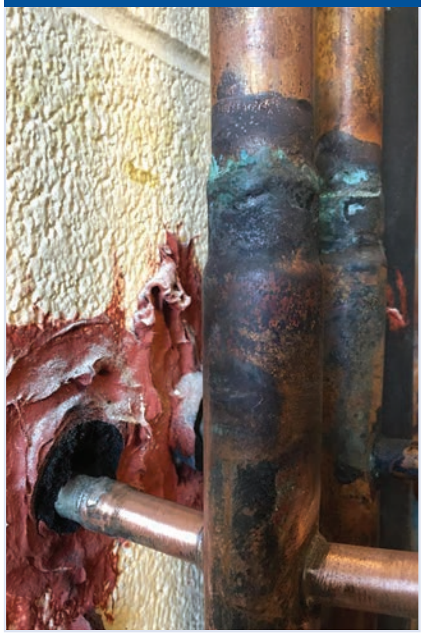


FIGURE 1 Pipes exiting a shaft.

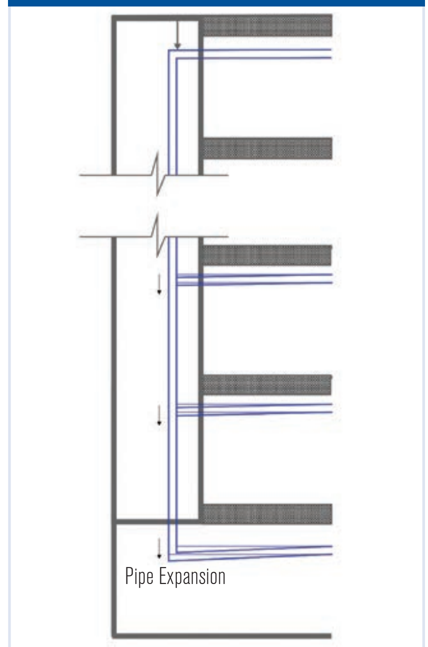


TABLE 1 Coefficients of thermal expansion, allowable stress and stiffness.

MATERIAL	EXPANSION[1]	S_A[2]	E[3]
Steel A53B ERW or Seamless	0.76	22,500	27.50
Stainless Steel	1.12	19,300	28.55
Copper	1.14	13,500	17
PVC/CPVC	4.20	1 to 2,000[5]	0.42
Polypropylene	7.20	Note 5	0.13
RTRP aka GRP or FRP[4]	1.08 to 1.57	2,500	1

1. Per the *2016 ASHRAE Handbook—HVAC Systems and Equipment,* p. 46.9, Table 7, expansion values are in in. per 100 ft (30 m) per 100°F (56°C). The *Handbook* shows these values in in. per (10^6 in. × °F). In this table they are converted to in. per 100 ft (30 m) per 100°F (56°C).
2. S_A = Allowable stress (psi). Values are from *2016 ASHRAE Handbook—HVAC Systems and Equipment,* p. 46.1. Furnace welded A53 steel is rated at 16,900 psi (117 MPa), and the *Handbook* suggests using 15,000 psi (103 MPa) for steel pipe.
3. E = modulus of elasticity (× 10^6 psi) or Young's modulus (10^6 psi), aka stiffness. Values are from *2016 ASHRAE Handbook – HVAC Systems and Equipment,* 46.9, Table 7.
4. RTRP is the most generic and stands for reinforced thermosetting resin pipe. Glass reinforced plastic (GRP) and fiber reinforced plastic (FRP) are limited to pipes with glass fiber filaments, which are by far the most common. But, RTRP also includes other filaments such as carbon fiber or carbon and other fiber types. The values in this table are based on glass fiber reinforcement. As a rule, vinyl ester binding is best for corrosion resistance (e.g., fume exhaust ducts), and epoxy resins may be best for applications that require high strength.
5. S_A varies greatly with temperature.

PHOTO 2 Plastic pipe bowing due to expansion.

IMAGE BY BRIJESH PANCHAL (IMEG)

FIGURE 2 Pipe in shaft from basement to penthouse.

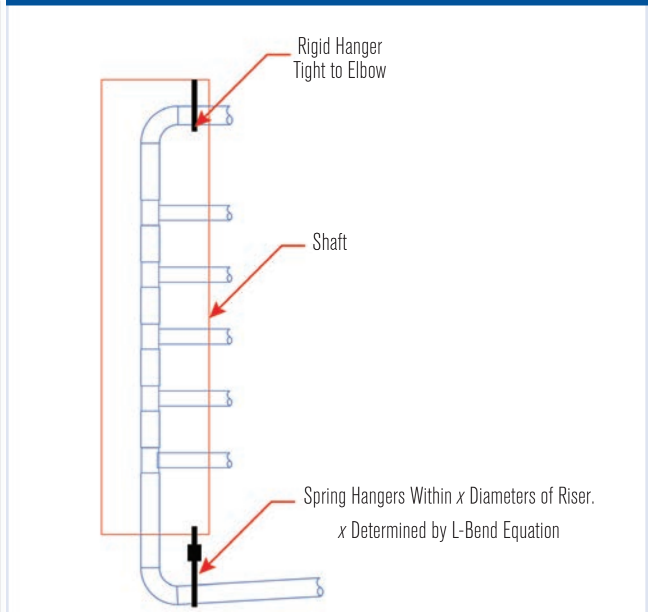


IMAGE BY BRIJESH PANCHAL (IMEG)

PHOTO 3 Alignment guide.

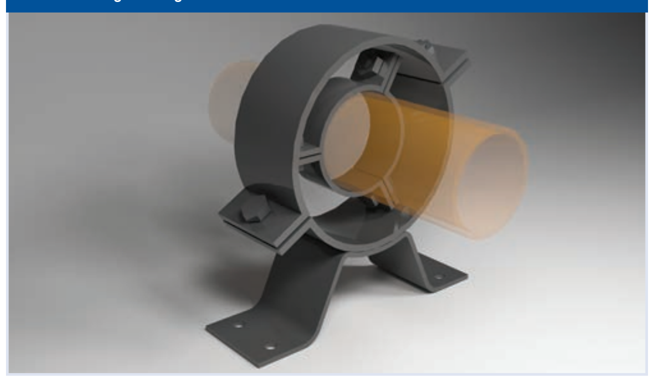


IMAGE BY BRIJESH PANCHAL (IMEG)

Systems and Equipment, Chapter 46. This is the most reliable and maintenance-free of all the options, but it takes up valuable room in shafts. It is important that the designer indicate where the piping will be anchored if the movement needs to happen only in particular directions. This is an excellent option for situations where pipes go from the basement to the penthouse with no taps at the individual floors (*Figure 2*), but can also be used inside shafts if there is room.

The second option is expansion joints. There are two common types of expansion joints: slip joints (aka packed expansion joints) and bellows joints. Slip joints consist of a pipe inside another pipe, and they telescope with a gasketing material between them to eliminate leakage (*Photo 4*).

These are common where large lateral movement must be accommodated, often in long steam tunnels, and are suitable for high temperatures and pressures. They do, however, require periodic maintenance of the sealing material. And, if located in a shaft, each slip joint will require a fire rated access door. If they need to be repacked under pressure, isolation valves in the packing stems may be needed. This type of joint is very resistant to catastrophic failure, which is an advantage over bellows joints.

Bellows joints (*Photo 5*) are manufactured from corrugated stainless steel or bronze, often with a braided metal exterior wrap to add strength and safety. They may include alignment guides, in which case they are called expansion compensators. Interior liners are common in steam joints to avoid concerns about erosion of the bellows and to minimize noise. An unlined steam bellows joint can be frightening to go near in a steam tunnel because it can sound like Conan the Barbarian is swinging a gigantic whirly tube (see https://tinyurl.com/yaz96avc). It is important to design bellows systems with proper alignment guides and to be sure that axial motion is not more than they can accommodate; otherwise, the possibility exists of the joints failing.

A variation of the bellows joint is the flexible expansion loop. This type of joint uses two bellows joints in a U-bend arrangement (*Photo 6*). Movement is perpendicular to the joints, which allows for more movement than in axial bellows joints. This style takes up valuable shaft space for the offsets, but not as much space as is needed for U-bends made with just pipe. It also greatly reduces anchor forces compared to other options.

Flexible mechanical couplings (*Photo 7*) offer another option. The advantages of this approach are that little or no extra shaft space is required (depending on insulation thickness), often there is no added cost, and little or no increased risk of a failure. The concerns about pipe breakage or becoming too eccentric to conform with firestopping UL listings are easily dealt with by locating anchors near each branch that leaves the shaft and having the expansion occur between branches. A few years ago, mechanical coupling systems also became available for low pressure steam.

Example 1

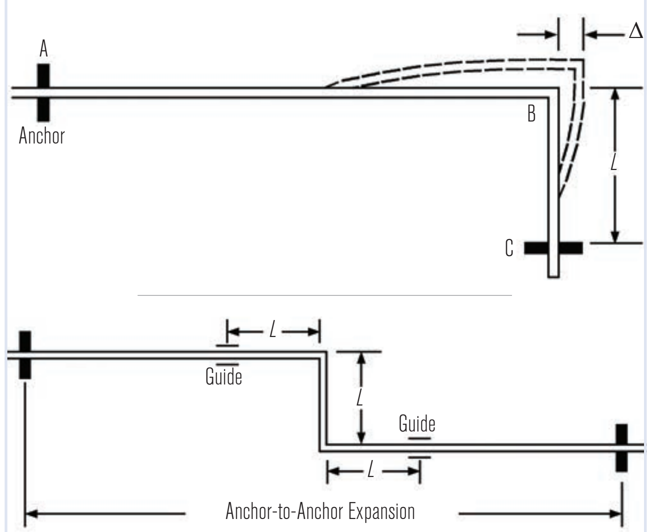
6 in. (152 mm) Diameter Schedule 40 Steel Steam (12 psig ≈ 245°F [83 kPa ≈ 118°C]) Pipe Going from Basement to Penthouse, 10 Stories, 14 ft/story (4.3 m/story)

$$(245°\text{F} - 70°\text{F}) \times 140\text{ ft} \times \frac{0.76\text{ in.}}{100°\text{F} \times 100\text{ ft}} = 1.86\text{ in.} \qquad (2)$$

The total expansion for 140 ft (43 m) of steel pipe in the shaft is 1.86 in. (47.2 mm). If we choose to rigidly support the pipe at the penthouse (i.e., hang the pipe) and allow the pipe to expand into the basement, we effectively turn the expansion into a simple L-bend calculation (refer to *2016 ASHRAE Handbook—HVAC Systems and Equipment*, Chapter 46, p. 46.11). If the pipe expands into the basement, the first few hangers need to be able to permit this expansion. Otherwise, the expansion forces are great enough that it could break the hanger.

Using Equation 5 of the *2016 ASHRAE Handbook—HVAC Systems and Equipment*, Chapter 46, p. 46.11, we can calculate the location of the first rigid hanger. Using this equation, the first rigid hanger should be at least 17 ft, 8 in. (5.4 m) in from the shaft piping. If 6 in. (150 mm) diameter piping is spaced at 12 ft (3.7 m) o.c., the first

FIGURE 3 (TOP) L-bend. **FIGURE 4 (BOTTOM)** Z-bend. (Source: *2016 ASHRAE Handbook—HVAC Systems and Equipment,* Chapter 46.)



Distance from guides, if used, to offset should be equal to or exceed the length of offset. Offset piping must be supported with hangers, side plates and spring hangers similar to those for L-bends.

two hangers should be spring hangers with 2 in. (51 mm) deflection to allow the pipe to expand. The third hanger can be rigid. The force due to the deflection on the third hanger at 17 ft, 8 in. (5.4 m) is approximately 2,655 lb_f (11 810 N) using Equation 7 of the *2016 ASHRAE Handbook—HVAC Systems and Equipment*, Chapter 46, p. 46.11. The forces at the third hanger will reduce as the hanger is moved away from the shaft.

Another option is to use intermediate flexible couplings with a rigid hanger at the bottom. This avoids the need for spring hangers.

Example 2

180°F (82.2°C) Maximum Steel Heating Water Pipe From Basement to Penthouse, Taps on Each Floor, 10 Stories at 14 ft/story (4.3 m/story)

PHOTO 4 Packed slip expansion joint.

IMAGE BY BRIJESH PANCHAL (IMEG)

PHOTO 5 Bellows joint with braided stainless steel outer wrap.

IMAGE BY BRIJESH PANCHAL (IMEG)

PHOTO 6 Flexible U-bend.

IMAGE BY BRIJESH PANCHAL (IMEG) AND METRAFLEX

PHOTO 7 Flexible mechanical couplings in vertical piping.

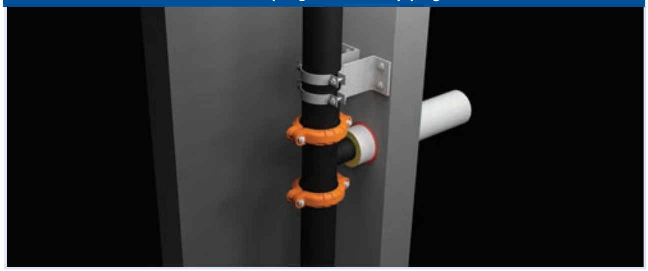


IMAGE BY BRIJESH PANCHAL (IMEG)

The expansion is (180 – 70°F) × 140 ft × 0.76/10,000 = 0.21 in. (5.3 mm) per floor, or 1.2 in. (31 mm) through the entire shaft. The pipe must not be allowed to move substantially at any branch to protect the penetrations. This gives us a few options. We could offset back and forth in the shaft at each floor and anchor near each penetration of the shaft to create a series of Z-bends. With this layout, each individual floor would only need to accommodate 0.21 in. (5.3 mm) of expansion. Using a 2.5 ft (763 mm) offset on each floor, the force at each anchor is only 680 lb_f (3025 N), which is acceptable in most situations.

TABLE 2 Authors' opinions of ratings of shaft options.

TYPE	COST	SPACE USED	SAFETY	ACCESS NEEDED
Bellows Joint	2	3	2	3
Slip Joint	2	3	3	1
Flexible Hose	3	2	2	3
L- or Z-Bend*	3	4	4	4
U-Bend	2	1	4	4
Flexible Coupling	4	3	4	4

1 = Poor, 2 = Moderate, 3 = Good, 4 = Excellent
*L- and Z-bend ratings assume that they occur at the top and/or bottom of the shaft, not inside the shaft as would be needed if there were takeoffs on each floor.
Ratings are the author's opinion.

Summary

Designers should develop a plan to accommodate expansion and contraction of pipes. Often, details of anchors and the ability to resist forces are left to the contractor, but a viable method should be described on drawings/in specifications. This column summarizes advantages and disadvantages of various methods of accommodating pipe expansion in shafts. ■

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