Quick Check on Piping Flexibility

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ABSTRACT

One major requirement in piping design is to provide adequate flexibility for absorbing the thermal expansion of the pipe. However, due to lack of quick method of checking, pipings are often laid-out to be either too stiff or too flexible. In either case, valuable time and material are wasted. This paper presents some of the quick methods for checking piping flexibility. These methods include visual, hand calculation, and micro computer approaches. They are all quick and easy for designers to use in planning their layouts. Once the designers have taken care of the flexibility problem, the iterative procedure between the stress engineers and the designers become simpler. The project schedule can also be improved.

PIPING FLEXIBILITY

As the pipe temperature changes from the installation condition to the operating condition, it expands or contracts. In the general term, both expansion and contraction are called thermal expansion. When a pipe expands it has the potential of generating enormous force and stress in the system. However, if the piping is flexible enough, the expansion can be absorbed without creating undue force or stress. Providing the proper flexibility is one of the major tasks in the design of piping system.

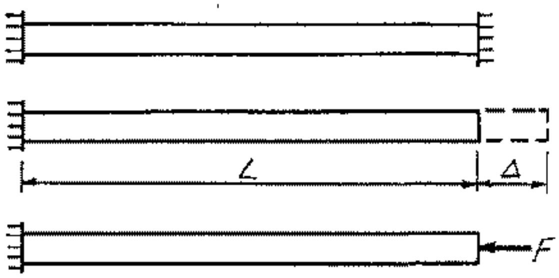
Piping is used to convey a certain amonut of fluid from one point to another. It is obvious that the shorter the pipe is used the lesser the capital expenditure is required. The long pipe may also generate excessive pressure drop making it unsuitable for the proper operation. However, the direct shortest layout generally is not acceptable for absorbing the thermal expansion.

Figure 1 shows what will happen when a straight pipe is directly connected from one point to another. First, consider that only one end is connected and the other end is loose. The loose end will expands an amount equal to

$$\Delta = e\ L$$

However, since the other end is not loose, this expansion is to be absorbed by the piping. This is equivalent to squeezing the pipe to move the end back an Δ distance. This amount of squezzing creates a stress of the magnitude

$$S = E\ (\Delta/L) = E\ e$$



Where,

Δ = thermal expansion, in
e = expansion rate, in/in
L = pipe length, in
S = axial stress, psi
E = modulus of elasticity, psi
A = pipe cross section area, in2
F = axial force, lbs

Figure 1

The force required to squeeze this amount is

$$F = A\ S = A\ E\ e$$

Take a 6-inch standard wall carbon steel pipe for instance, an increase of temperature from 70F ambient to 300F operating creates an axial stress of 42300 psi and an axial force of 236000 lbs in the pipe. These are excessive even though the temperature is only 300F. It is clear that the straight line direct layout is not acceptable to most of the piping. Flexibility has to be provided.

EXPANSION LOOP

Piping flexibility are provided in many different ways. The turns and offsets needed for running the pipe from one point to another provides some flexibility by themself. This inherent flexibility may or may not be sufficient depending on the individual cases. Additional flexibility can be provided by adding expansion loops or expansion joints. In the straight line example discussed above, the stress can be reduced by a loop installed as shown in Figure 2 or by an expansion joint as shown in Figure 3.

The idea in Figure 2 is to provide some pipe perpendicular to the direction of expansion. In this way when the pipe expands it bends the loop leg first before transmitting any load to the anchor. The longer the loop leg the lesser the force will be created. The force created is inversely proportional to the cube of the loop length and the stress generated is roughly inversely proportional to the square of the loop length. The loop sometimes can take considerably more space and piping than what is available, or economically justifiable. This is especially true for large high temperature low pressure pipings. In this case the better method is to use expansion joint. Expansion joints are more sophisticated than the pipe loops which are just extra lengths of the same piping. For this and

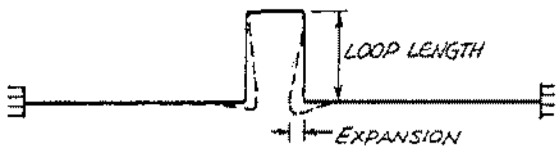


Figure 2

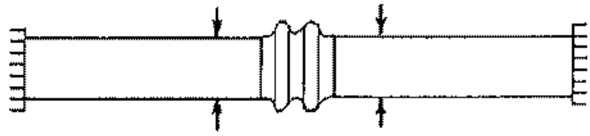


Figure 3

other reasons, engineers tend to favor piping loops over expansion joints. However, expansion joints can be used effectively in many applications when they are properly designed. One of the major requirements in the design of expansion joint system is to install sufficient restraints for maintaining the stability. This article deals mainly the loop approach.

THE CRITICAL PATH

In designing a plant, the piping is generally routed or laid-out by the piping designers then checked by the stress engineers as shown in figure 4.

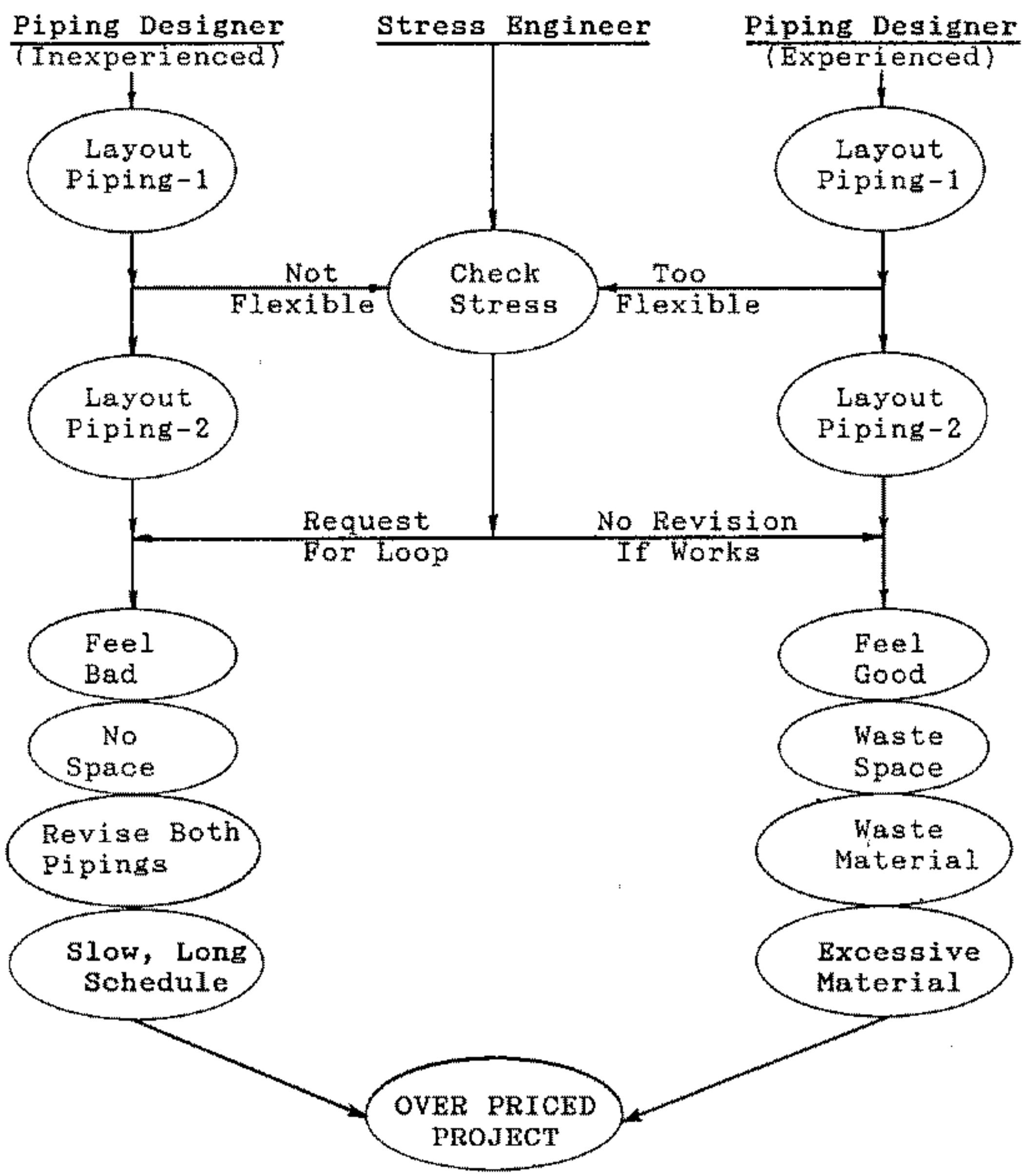


Figure 4

There is a marked difference in the layout done by the experienced and the inexperienced designers. The experienced designers know the importance of the flexibility. However, they tend to provide too much flexibility in contrast to the inexperienced ones who tend to provide little flexibility. In either case, the result is an over priced project.

The layout done by an inexperienced designer is normally too stiff because the designer does not know how or too timid to add loops or offsets. If a piping system is too stiff, the stress engineer will almost certain to find it out. The stress engineer will send the design, with recommended loops, back to the designer for revision. At this time, the designer have made some more layouts in the same area making the revision very difficulty. On the other hand, a layout done by an experienced designer often contains the loops which are excessive or not needed. The excessive loops are normally maintained without revision, becuase it is a common prctice not to change something which works. The experienced one might have saved the manhour needed for the revision. The cost of the excessive loops can be prohibitive.

The cost of the project can be reduced substantially if the right amount of flexibility is built in the piping at the initial layout stage. This requires some quick methods which can be used by the designers to check the piping flexibility.

VISUAL CHECK

The visual check is the first important examination on anything we do. If the design looks strange, then most likely something is wrong with it. By now we at least know that we can not run a piping straight from one point to another. This also applies to the situation when there are two or more line stops installed at a straight header as shown in Figure 5. The line stop or axial stop acts directly against the expansion of the pipe. When two axial stops installed on the same straight leg, the thermal expansion of the pipe located between the stops has no place to relieve.

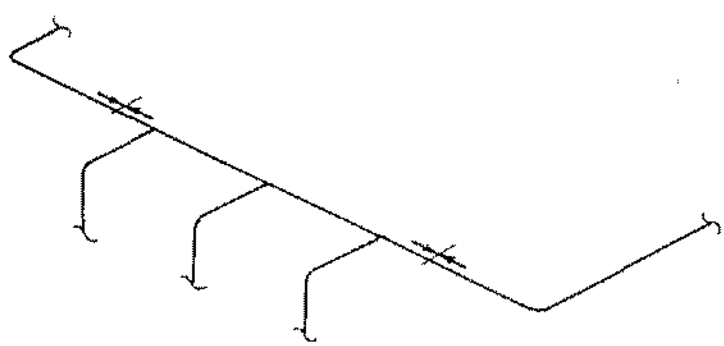


Figure 5

The visual check of the piping flexibility is to look for the pipe legs located in the direction perpendicular to the line connecting the two anchor or other restraint points. The length of the leg is the direct measure of the flexibility. Therefore, the key is to locate the availability of the perpendicular leg and to determine if the length of the leg is sufficient. The required leg length can be estimated by the rule of thumb equation (1) derived by the guided cantilever approach, for steel pipes.

$$\ell = 5.5\sqrt{D\Delta} \qquad (1)$$

where,

ℓ = leg length required, ft
D = pipe outside diameter, in
Δ = expansion to be absorbed, in

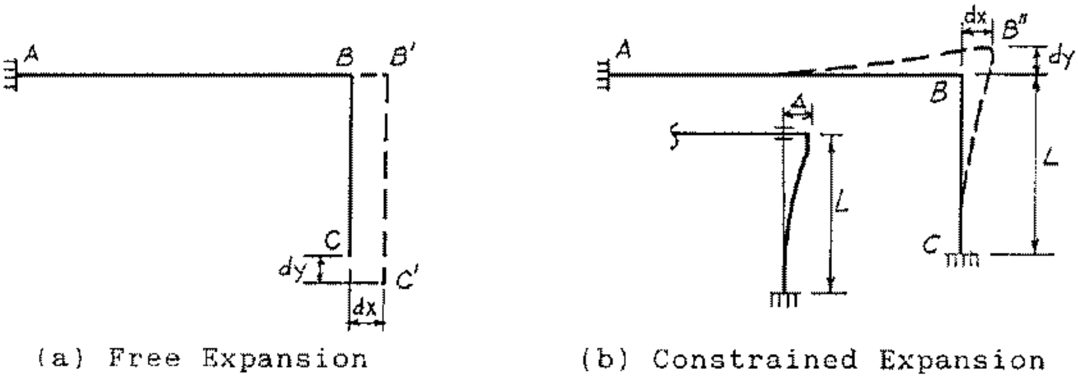
To use Equation (1) efficiently the expansion rate of the pipe has to be remembered. Table 1 shows the expansion rates of carbon and stainless steel pipes at several operating temperatures. The rate at other temperature can be estimated by proportion. By combining Equation 1 and Table 1, the designer can estimate the leg length required without needing a pencil. For instance, an 80 feet long 6-inch carbon steel pipe operating at 600F expands about 4 inches which requires a 30 feet leg to absorb it. It should be noted that an expansion loop is considered as two legs with each leg absorbs one half of the total expansion.

Table 1

		Expansion Rate, in/100 ft pipe				
	Temp,F	70	300	500	800	1000
Carbon Steel		0	1.82	3.62	6.7	8.9
Stainless Steel		0	2.61	5.01	8.8	11.5

HAND CALCULATION

There are several simplified calculations can be performed quickly with hand. The most popular one is the so called guided cantilever approach. The method can be explained using the L-bend given in Figure 6 as an example. When the system is not constrained the



(a) Free Expansion (b) Constrained Expansion

Figure 6

points B and C will move to B' and C' respectively due to thermal expansion. The end point C moves dx and dy respectively in X- and Y- directions, but no internal force or stress will be generated. However, in the actual case the ends of the piping are always constrained as shown in Figure 6(b). This is equivalent in moving the free expanded end C' back to the original point C forcing the point B to move to B". The dx is the expansion from leg AB, and dy from leg CB. The deformation of each leg can be assumed to follow the guided cantilever shape. This is conservative because the end rotation is ignored. The force and stress of each leg can now be estimated by the guided cantilever formula. The leg AB is a guided cantilever subject to dy displacement and leg CB a guided cantilever subject to dx displacement respectively.

From the basic beam theory, the moment and displacement relation of a guided cantilever is

$$M = \frac{6\,E\,I}{L^2}\,\Delta\,, \qquad F = \frac{2\,M}{L} \tag{2}$$

For thin wall pipes, Equation (2) can be further reduced. By using $I = \pi r^3 t$ and $S = M/(\pi r^2 t)$, the above equation becomes

$$S = \frac{6\,E\,r}{L^2}\,\Delta = \frac{E\,D\,\Delta}{48\,\ell^2} \tag{3}$$

where,
- S = thermal expansion stress, psi
- E = modulus of elasticity, psi
- r = mean radius of the pipe, in
- Δ = total expansion to be absorbed, in
- L = length of the leg perpendicular to , in
- ℓ = length in feet unit, ft
- D = outside diameter of the pipe, in

Equation (3) is a convenient formula for the quick estimation of the expansion stress. By pre-setting E=29.0x10 psi and S=20000 psi, Equation (3) becomes Equation (1) used in finding the leg length required for steel pipes.

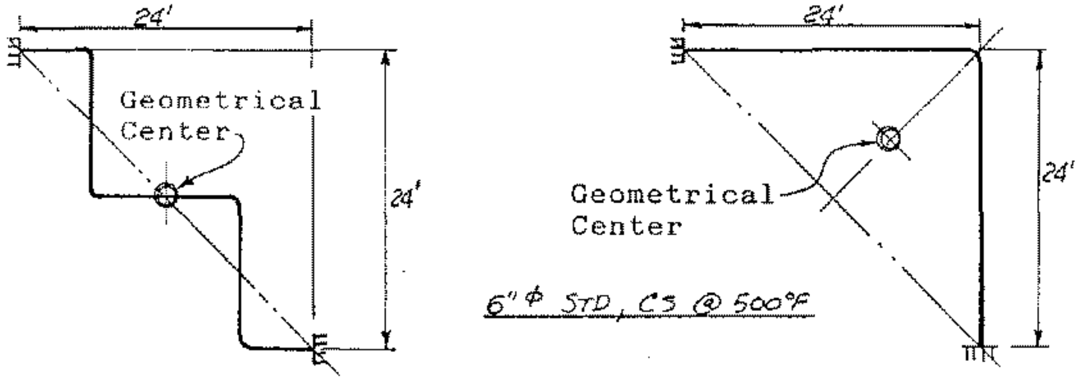
The other formula can be used for the quick check is the one given in ANSI B31 Piping Codes. The Code uses Equation (4) as a measure of adequate flexibility, subjects to other requirements of the Code.

$$\frac{D\,y}{(L-U)^2} < 0.03 \tag{4}$$

where,
- D = outside diameter of the pipe, in
- y = resultant of total displacement to be absorbed, in
- L = developed length of piping between anchors, ft
- U = straight line distance between anchors, ft

Equation (4) is actually equivalent to Equation (1), if (L-U) is considered as the perpendicular leg length.

Equation (4) has to be used with great care, because the same extra length of pipe can have very diferent effects depending on the ways the pipe is laid-out. Normally more flexibility will be achieved if the pipe is placed farther away from the elastical or geometrical center. For instance with the same extra length of piping, when it is laid-out as shown in Figure 7 (a) it has much higher flexibility than when it is laid-out as in Figure 7 (b). Designers often have the misconception about the amount of flexibility can be provided by the zig-zag arrangement. Due to the extra elbows placed in the layout, one tends to think that additional flexibility should have been created. Unfortunately, the additional flexibility from the elbows is not enough to compensate the loss of flexibility due to the placement of pipe toward the geometrical center.



(a) Stress = 13764 psi (b) Stress = 8226 psi

Figure 7

MICRO COMPUTER APPROACH

Currently most large engineering companies use CAD system to do the piping design. It is possible that one day the system will be able to tell you if you need any extra flexibility, as soon as you place the line on the screen. However, before that time comes, we still have to survive the current situation to be able to see the good thing coming. Nevertheless, the technology of the micro computer has advanced enough for us to perform accurate flexibility analyses right beside the drafting board.

The micro computer programs are normally so user friendly that it takes only a couple of hours to master their usage. With respect to the flexibility check, a piping designer can do almost as good a job as a stress engineer can. What it is needed is to enter the pipe and geometrical information to the program which will almost instantly give you the forces and stresses expected in the system. From that information, the designer can then decide if additional loops or offsets are required.

The use of the micro computer differs substantially depending on the individual program setup. Each program has its preferred method of entering the data and generating the output. Appendix A shows the sample operating procedure using PENG.QFLEX program to analyze the simple system given in Figure 8.

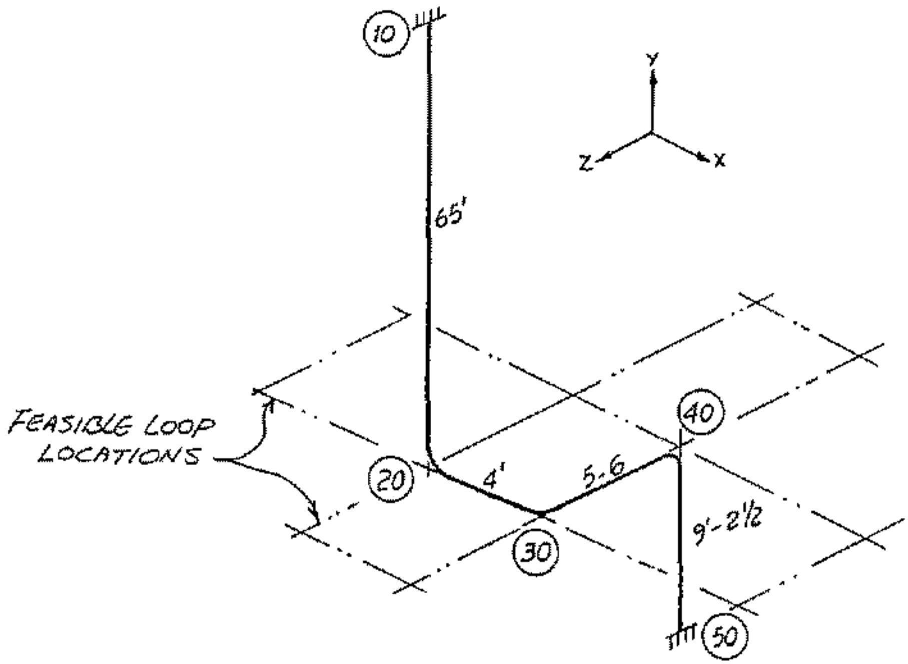


Figure 8

Once it is determined that an expansion loop is required, the loop can be placed at one of the feasible locations before the area is congested by other layouts. This also saves the iterative process between the piping designers and the stress engineers.

CONCLUSION

The traditional piping design procedure depends heavily on the stress engineer to check piping flexibility. With the availability of quick methods in checking the flexibility, the designer can now layout the pipe to provide the proper flexibility at the very beginning. This substantially reduces the number of iterations required between the piping designer and the stress engineer. The cost of the plant can be reduced by the shorter schedule and less manpower required.