must be used in the U-bend to take up the deformation, Δ. When welding fittings are used, the radii should be six times the outside diameter of the pipe. One other restriction is that the pipe should not be heavier than extra strong.

Manufacturers of pipe, or pipe fittings, often publish excellent treatises on the simplification of expansion problems. It is suggested that the engineer obtain such publications and also a text or handbook[6] on the subject before attempting to solve a problem on flexibility.

HANGERS AND SUPPORTS

In the preceding section, Equation 3 was developed to give the force of total constraint. This equation is appropriate regardless of the sign of Δt, positive or negative. It did not, however, allow for any bending moment but was for straight compression or tension.

TABLE 21. EQUATIONS FOR BENDING STRESS AND DEFLECTION BETWEEN SUPPORTS

TYPE OF SUPPORT	BENDING STRESS, PSI S	DEFLECTION, INCHES Y
Single span (free ends).....	$S = \frac{0.75WL^3D}{I}$	$Y = \frac{22.5WL^4}{EI}$
Continuous Line.....	$S = \frac{0.5WL^3D}{I}$	$Y = \frac{4.5WL^4}{EI}$

where

W = Total weight (pipe, fluid, etc) pounds per foot.
D = O. D. of pipe, inches.
L = Length of span, feet.
E = Modulus of elasticity, pounds per square inch.
I = Moment of inertia, (inches)^4.
$I = \frac{\pi}{64}(OD^4 - ID^4)$, O. D. and I. D. in inches.

If the compressive force is great enough, or if the line is long enough, a slight eccentricity of the load application will cause a *buckling* of the line. This buckling is identical with the action of a column under excessive compression. In fact, a pipe line in compression is identical to a column. Column criteria can therefore be used for selecting the action of supports to resist lateral thrust.

A common equation for determining safe column loads is Euler's formula:

$$S = \pi^2 E \left(\frac{k}{l}\right)^2 \quad \text{(for cast iron see Equation 6)} \qquad (5)$$

where

S = allowable column load, pounds per square inch.
k = radius of gyration, inches.
l = column length, inches.

$$k^2 = \frac{I}{A} = \frac{OD^2 + ID^2}{16}$$

This equation is not used for column construction but is sufficiently accurate for the work of a heating engineer.

The equation is modified for cast iron because of its poor tensile strength. It is generally acceptable to use one-half the value of S from Equation 5 for cast iron, so it becomes

$$S^1 = \frac{\pi^2 E}{2}\left(\frac{k}{l}\right)^2 \quad \text{for cast iron.} \qquad (6)$$

It is permissible to allow the l/k ratio for steel to go as high as 120, but for cast iron the desirable maximum is taken as 70. It is not to be understood that a fracture will occur at l/k ratios in excess of those given, rather it is to be understood that lateral support should be given for those ratios and for those magnitudes of stress. If an expansion joint is used, this will, of course, relieve the compressive stress.

Example: For the problem given in the above section, the constraining force for a 1 in. pipe was 9630 lb. What is a required spacing for lateral support for this pipe?

Answer: Using Euler's formula, Equation 5 gives

$$S = \pi^2 E \left(\frac{k}{l}\right)^2$$

so

$$l = \pi k \sqrt{E/S}$$

For a 1 in. Schedule 40 steel pipe

k = 0.4205 inches.
E = 30,000,000 pounds per square inch.
S = 9630 ÷ 0.494 = 19500 psi
l = 51.8 inches.

Therefore, lateral supports on six foot centers would be adequate.

The other type of load requiring some support is the bending stress due to the weight of the pipe, its insulation, and of the fluid being carried. There is also the bending moment that may be caused by the flexure of the pipe. For this chapter however, the flexure loading will not be treated for the reason of complexity, as previously stated for the problem of expansion.

Since hangers should always be designed to take the bending moment (including buckling) from the pipe, it is necessary to design the hangers or supports for the maximum bending stress. Even with perfect support spacing there will be some sagging; therefore, the supports should be on a gradient if it is necessary to prevent pockets. Such a condition arises for condensate piping.

Typical bending and deflection equations are given in Table 21 in order that supports can be properly sized, and if necessary, pitched. These equations are typical beam equations. If more complex loadings exist, proper beam equations can be applied. Such equations are found in standard texts on mechanics of materials.

By application of the equations given in this section and the section of expansion and flexibility, it is possible to determine the proper location and type of support for straight lines. The types are anchors and hangers.

Anchors are used to guide the expansion (sliding anchors) or to fix the pipe. They are needed to take the stress out of the line and translate the stresses to the foundations. In that way all stress can be taken out of