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# Span Limits for Elevated Temperature Piping

*Pipe deflection due to self-weight quite often governs in the determination of the spacing between supports. Methods are readily available for calculation of elastic deflection of the pipe. However, such methods are not available for calculation of long-term deflection due to creep, which can be many times the initial elastic deflection for pipe operating in the creep regime of the material. Closed-form solutions for simple span conditions are presented which can be used by the analyst to develop charts for specific applications. These solutions provide insights into the problem of establishing span limits for elevated temperature pipe. [50094-99/30000901101-X]*

## Introduction

While pipe deflection is not limited by ASME B31.1 or B31.3, it quite often governs support spacing of pipe. While the pipe may be strong enough to span between supports, excessive sag is generally considered undesirable for several reasons, including the fact that personnel tend to lose confidence in the design of piping exhibiting large deflection. A general rule of thumb in design of process piping is to limit the deflection to 1/2 in. (13 mm).

While calculating the deflection of piping that behaves elastically is relatively trivial, determining the deflection of pipe operating well into the creep regime for the material of construction poses problems for the designer. Span tables, piping stress analysis programs, and generally available design methods only consider the elastic deflection of pipe. While creep deflection, over time, can be dramatically more than the initial elastic deflection, simplified methods to determine the development of the pipe sag over time are not available. Various approaches have been considered, such as limiting the allowable sustained longitudinal stress at elevated temperatures to something less than the code allowable stress. Note that this is essential to prevent excessive creep deflection at very high temperatures.

In developing the design basis for stainless steel pipe to operate at temperatures up to 1800°F (980°C) for the Marble Hill Nuclear Reactor Pressure Vessel Annealing Demonstration Project, it was apparent that accumulation of creep deflection required consideration in establishing the maximum permissible span between pipe supports. To establish these limits, closed-form integrals to calculate creep deflection of pipe spans were developed, which could readily be solved on available math software, such as MathCad. These integrals, and their derivation, are provided in the Appendix. They are based on a steady-state creep law, Norton, where creep strain rate is equal to a constant times stress to the power of  $n$ . The exponent  $n$  depends on material and temperature, but a value of about 6 can be expected for high-temperature austenitic stainless steel.

## Creep Deflection Equations

Creep deflection under bending was calculated per Finnie and Heller [1] as follows. The same basic assumptions as in elastic beam analysis were made (e.g., shear deformation neglected, plane sections remain plane, and small displacements). It is also assumed that the creep rate in tension and compression, at the same stress level, is the same.

The Norton creep equation is assumed, as follows:

$$\dot{\epsilon}_c = B\sigma^n \quad (1)$$

The stress in a beam section redistributes due to creep because of the sensitivity of creep rate to stress. The stress on the outer fiber of a beam under steady-state creep condition may be calculated as follows:

$$\sigma_{c1} = \frac{Mh}{2I_c} \quad (2)$$

The outer fiber strain in a beam is proportional to the radius of curvature, as follows:

$$\epsilon_{c1} = \frac{y_1}{\rho} \quad (3)$$

Combining Eqs. (1), (2), and (3), results in the following equation:

$$\left[ \frac{Mh}{2I_c} \right]^n = \frac{y_1}{\rho B} \quad (4)$$

The inverse of the radius of curvature can be replaced with the second derivative of deflection,  $d^2y/ds^2$ . The resulting equation is integrated twice to calculate deflection, with appropriate inclusion of constants of integration and due consideration to changes in direction of curvature.

Equations are provided in the Appendix for three conditions: simply supported beam, cantilever beam, and beam with fixed ends.

## Discussion

The evaluations provided insights into the problem of establishing allowable spans for high-temperature piping. One very interesting finding at very high temperatures was that the allowable span was relatively insensitive to the allowable deflection and the constant  $B$  in the creep equation, within reasonable limits. It is the sensitivity of creep rate to stress, and, in turn, the sensitivity of stress to span length, that dominates the creep deflection problem. Considering that stress is proportional to the span length to the second power, and assuming that creep strain rate is proportional to stress to, say, the sixth power, knowing that deflection is proportional to strain, we find that creep deflection rate is highly sensitive to span length.

Creep deflection goes up exponentially with span length, so that beyond a given length, at least at relatively high temperatures, deflection is unacceptable, and below that length, deflection is not particularly significant. Figure 1 shows the creep deflection of a simply supported Schedule 10S 304L stainless steel line, assuming 30 lb/ft (44 kg/m) steel and insulation weight with vapor as the contents, as a function of length at 1500°F (815°C) and for a duration of 1000 h. One can see that, between span lengths of 17

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# Design Of Elevated Temperature Piping Pvp Vol 86

**Jin-Ying Zhang**



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