Comments on Flexibility Analysis (June 2004)

The American Society of Mechanical Engineers (ASME) B31 Code for Pressure Piping was developed with the expectation that piping system designers would be familiar with the concept of flexibility. For this reason the B31 Codes never described or discussed in any depth the intention of performing or the results expected from a flexibility analysis. The flexibility equation, also referred to as the thermal expansion or displacement stress equation,

$$S_E = (S_b^2 + 4\ S_t^2)^{1/2}$$

was incorporated into the 1955 Edition of B31.1 in Section 6, Chapter 3, Expansion and Flexibility. In 1955 the B31.1 book had different sections for different applications, i.e., Section 1 for power piping, Section 2 for industrial gas and air piping, Section 3 for refinery and oil transportation piping, Section 4 for district heating piping, and Section 5 for refrigeration piping. But prior to 1955, in 1952, the B31.8 Gas Transmission and Distribution Piping book was published, initiating the publication of the separate applications books we have today, i.e., B31.1 Power Piping, B31.3 Process Piping, B31.4 Liquid Transportation Piping, B31.5 Refrigeration Piping, and B31.9 Building Services Piping. Each of these applications books, when published, incorporated the flexibility equation following a B31 code model outline developed in the 1950's. B31.8 also incorporated the flexibility equation even though B31.8 did not follow the model outline owing to the fact that B31.8 was published prior to the development of the B31 model outline.

The allowable flexibility stress-range for the 1955 Edition of B31.1 was based on the expectation of elevated temperature operation and ductile behavior, and first introduced the concept of self-springing or shakedown to ASME pressure component design. Generally, the flexibility allowable stress-range was permitted to approach two times yield. However, the pipeline codes, B31.4 and B31.8, never adopted the twice yield allowable stress-range (shakedown) concept because it was expected that pipelines would experience nonductile behavior. Code revisions over the years since 1955 have not served to clarify the concept of flexibility and in many ways have obscured it. For example, B31.1 deleted a stress equation which implied the methodology typically used for flexibility design.

The purpose of performing a flexibility analysis is to determine that, barring interferences and assuming a supportable geometry, the anchor-to-anchor piping configuration (layout) is acceptable. Adequate flexibility is required to avoid an expansion (or contraction) induced fatigue failure and to limit anchor loads on equipment. A flexibility analysis typically (and traditionally) evaluates the range of stresses encountered by piping system service startup and shutdown. It is generally assumed that the startup-shutdown stress-range will bound the other thermal expansion or displacement stress-ranges. The piping flexibility is evaluated between equipment and structural anchors without locating any intermediate supports. Weight stresses, then, would not be known. It is presumed that the intermediate supports for weight and other loads can be added after determining that a piping system has adequate flexibility without significantly increasing the flexibility stress-ranges. This is reflected in the circa. 1955 B31 books having an allowable thermal expansion stress-range

$$S_A = f(1.25S_c + 0.25S_h)$$

and permitting an additional thermal expansion stress-range allowance of S_h - S_L, when the stresses due to weight and other sustained loads, S_L, were known.

After the flexibility analysis has determined that the piping has adequate flexibility, using the allowable thermal expansion or displacement stress-range, S_A, then span tables and/or engineering judgement is used to locate intermediate supports for weight and other loads. If the thermal displacements at a proposed support point are negligible (i.e., very small), then a rigid support can be located at that point. If the vertical thermal displacements are significant at locations where weight supports are proposed, springs (variable or constant) can be used. If the lateral thermal displacements are significant at locations where lateral supports are proposed, gapped supports usually can be used. By use of support types that offer minimal restraint throughout the startup-shutdown excursion, the flexibility stress-range is not significantly increased and could be expected to be bounded by the additional thermal expansion allowance, S_h - S_L.

The entire flexibility design and analysis process assures that the effects of fatigue due to thermal expansion, or more generally the restraint of free-end displacements, are minimized. However, some caution in performing the flexibility analysis is necessary to see that other frequently occurring normal and abnormal operating condition stress-ranges do not envelope the startup-shutdown stress-range or to see that supports do not unduly restrain the load induced expanding (or contracting) piping system.