assumes a rigid support has a stiffness of 1E12 lbf/in (1.8E14 N/m).

Tall supports, especially supports on elevated pipe racks, have significantly less stiffness than shorter supports. In fact, the stiffness of a post-type support varies inversely with the height of the post raised to the 3rd power. A post that is twice as tall is 1/8th as stiff.

The second step to a more accurate thermal study is to accurately model friction between the pipe and the support. The friction force between two surfaces acts in a direction parallel to the surfaces but varies with the normal force perpendicular to the surfaces. The ratio between the normal force and the friction force (called the coefficient of friction) depends on the materials of the pipe, the clamp, and any shimming material placed between them.

This normal force includes not only the weight of the pipe but also the clamping force created by the vibration control clamp. This clamping force is equal to the sum of the preload on all the clamp bolts. Even with this clamping force, field experience has shown than pipe will slip through a clamp along its axis under thermal loads, even when the clamp is tightened and shimmed. If less friction force is required for a better thermal clamp design, special clamps can be used which minimize the clamping force or coefficient of friction and allow more slipping of the pipe.

The recommended modeling approach is summarized in Figure 7.

- Use an estimated stiffness for clamps based on field experience, finite element analysis, or even simple one-dimensional beam theory calculation.
- Apply friction forces to the model in the direction opposite of pipe movement.
- While the above two steps may take a bit more time at the front of the project, it will save time later on by avoiding rework.

API 618, 5th Edition, recommends that the piping vibration analysis and flexibility analysis be conducted by the same party. This helps balance modifications to reduce static stress with the potential for increasing vibrations and vibratory stress.

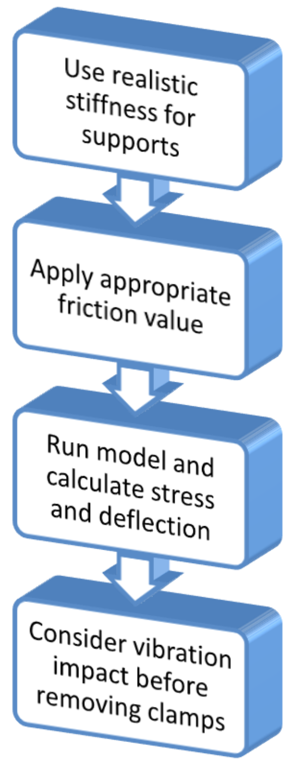

Figure 7. Recommend thermal modeling approach

5. Other Solutions

As mentioned in Section 3.2, one part of the solution for the Enogex facility was to use a special clamp to allow more thermal growth of the pipe through the clamps. BETA and others have developed thermal pipe clamps for this type of application (Figure 8). The clamp is useful because it is stiff enough to control vibrations caused by dynamic forces, but allows flexibility for large thermal growth.

In the Enogex case study, the clamps had to allow 5.5 inches (140 mm) of displacement on the discharge header. Traditionally clamps cannot support this displacement. The clamps and supports would experience failure (similar to Figure 2). BETA thermal clamps feature disk