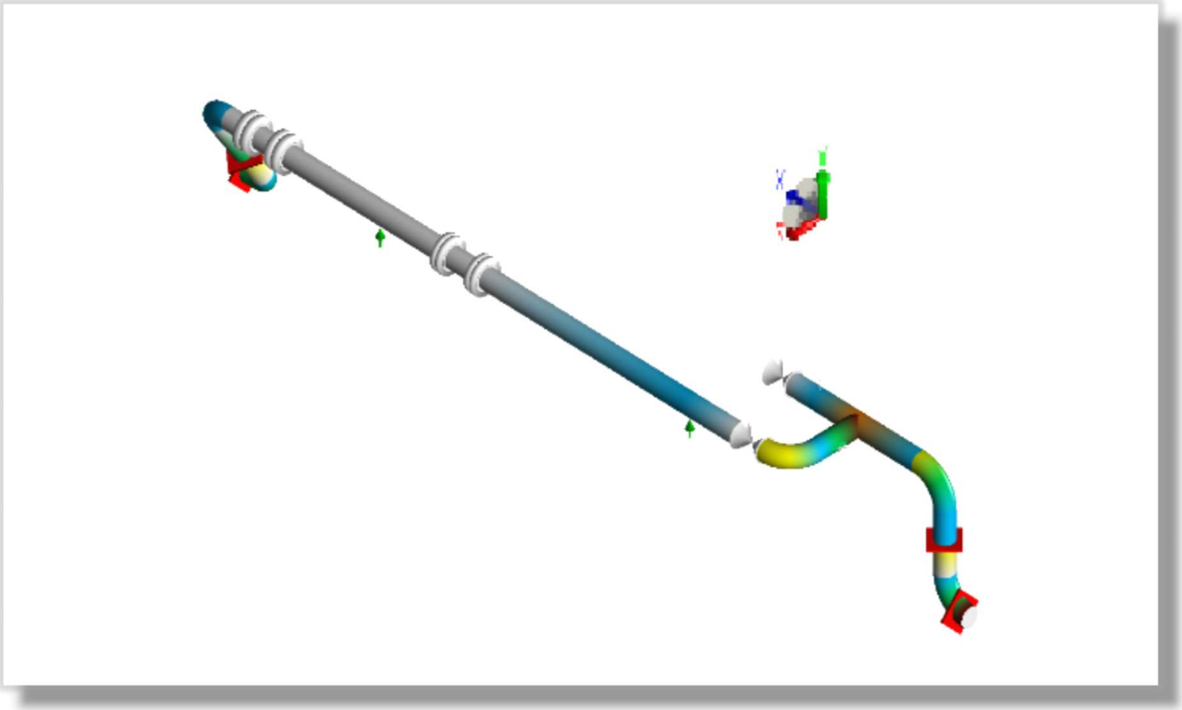
Pipeline Vibration Stress Cracking



Example Pipeline Diagram. HCI Systems, Inc.

Discussion

First, let me thank all the people for reading and commenting on my article "Hail Caesar....or not so much". If you have not yet read that one, please go to my LinkedIn page.

This article will discuss the phenomenon of pipeline stress cracking due to vibration. This is also known as fatigue cracking. Fatigue cracking of steel is a fairly well documented issue and most of the ASME B31.X codes discuss this and methods to include stress allowances to mitigate the effects. It is also well documented in the design of bridges where the traffic load is the forcing function. (Ok. That was my structural engineer side of me talking.)

The methodology discussed herein is valid for piping whether it is an oil or gas pipeline or piping at a chemical or power plant. Unfortunately many piping systems are designed without accurate information on vibration or are not aware of how pump and compressors can induce vibration by the shear movement of gas or liquid. It is usually a "failure" that initiates the question "how did this happen". Here is the story.

The Story

This image shown above is the Caesar II geometry diagram. Fatigue stress cracks were detected on the Tee fitting shown in red. As can be seen this fitting has a cantilever pipe and valve on the run side. This did not help matters. The client, upon detection of crack, had the wherewithal to go get a vibration probe/meter and obtained both displacement and frequency data on the cantilever pipe as it appeared to be oscillating. And, in fact, it was. The client forwarded the data and reference drawings to the analysis team and work began.

The analysis team created the geometry file in Caesar II and ran a few test runs to verify geometry and that the model would converge, which it did. Reality check was performed and no overstress nodes were reported, but the Tee was close. Ok. So now let's add the vibration. Now there are more than one way to do this. The one discussed below is more "traditional or old school" and a structural engineer may need to help out here because we will need to calculate the high and low stress valves due to pipe movement. Many pipe flexibility analysis program will accept a forcing function load to do this.

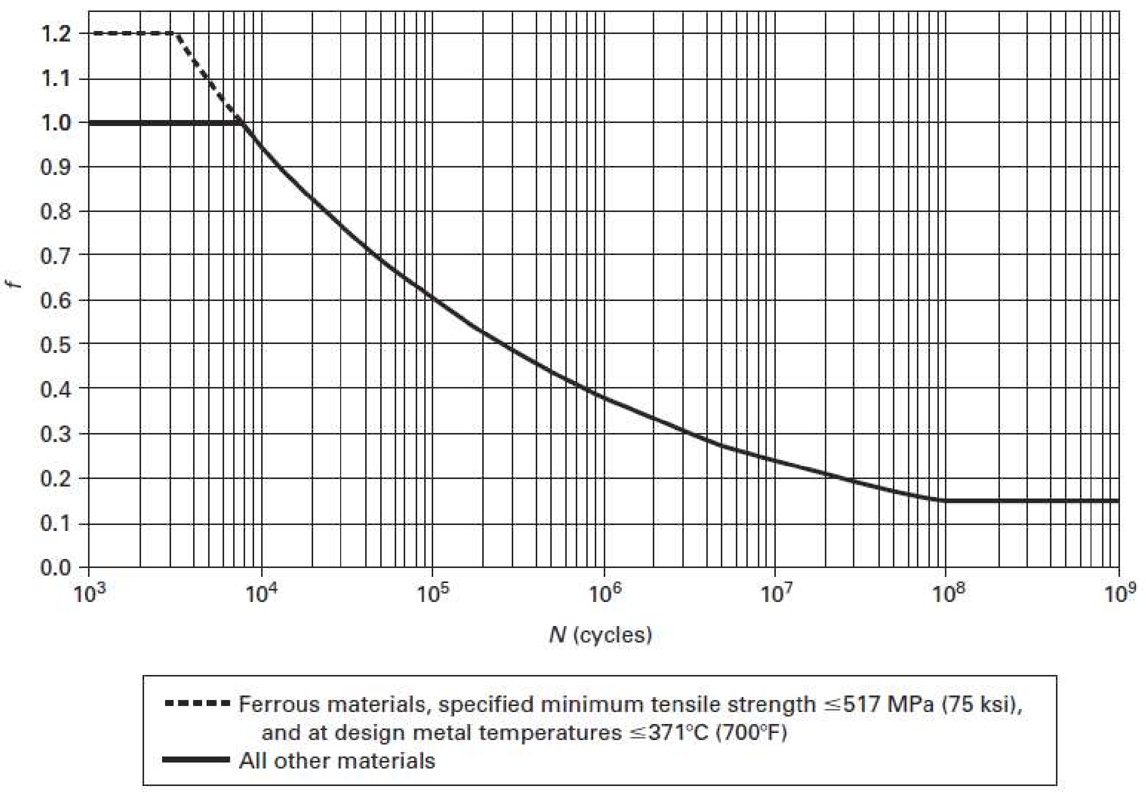
Old School

In this example, as the pipe moves up it tends to unload the Tee a little. And, as the pipe moves down, it tends to load the Tee. That is the stress range. It is a bending stress spike that is additive to any other bending stress in the same direction. In this case, it looks like Sz (read that as stress in around the z-axis). OK so far? Forgot statics in college? Well, by knowing the section modulus and length of the cantilever pipe and the displacement value, an engineer can tell you the stress spike at the Tee connection. Alright. So now what?

So now we have the Sz stress spike and add to that the static Sz stress due to dead loads. We are half way there. Now you need to refer back to whatever B31.X code you are working under and find the allowable stress curve for cyclic loads. In the case of B31.3, that would be Figure 302.3.5.

Figure 302.3.5 can be worked in two (2) ways. One can enter the figure with a known cyclic frequency and exit with a stress factor (f). Or one could enter the figure with a stress factor (f) and exit with the maximum number of cycles that stress factor can take before it will start to show fatigue cracks.

Fig. 302.3.5 Stress Range Factor, *f*



ASME B31.3 Figure 302.3.5

By stress factor (f) it is meant as:

$$Sa = f\,(1.25Sc + 0.25Sh)$$

where:

f = stress range factor, as determined from Fig. 302.3.5
Sa = allowable stress at cyclic load
Sc = basic allowable stress at min metal temperature expected
Sh = basic allowable stress at max metal temperature expected

For non-elevated temperature service, that is simplified as:

$$Sa = f\,(1.5Sc)$$

Example:

Sc = 20,000 PSI

Cycles = 10E07

Then f = 0.23

And Sa = 6,900 PSI

Since, in this example, the actual stress was about twice this number, it was destined to exhibit fatigue cracks. So what are take-aways from this article?

Take-Aways

1. Any piping component under similar cyclic loading frequency and displacement needs to have a Caesar II bending stress less than 6,900 PSI otherwise it will show fatigue cracks over time. Now everyone go back and check your stress reports. :)
2. More complicated piping geometries will require more complicated statics to get the stress spike value.
3. Most compressor and many pumping stations will exceed 10E07 cyclic loadings in their lifespan. In this example, it took only eight (8) months and 10E07 cyclic loadings for fatigue cracks to appear.

If you are in this situation or are concerned that you may be, please contact me at richgehse@hcisoftware.biz

Credits

Special thanks to the client and analysis team members for their professional working relationship on this project. If you are reading this you know who you are. No company and people names were used to protect anonymity.