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Markl, SIFs, and ASME VIII-2 Fatigue Design

Did you know that PRG has the only automated FEA Stress Intensification Factor (SIF) calculator in the world?

PRG software has been automatically calculating SIFs for varieties of piping components for more than fifteen years.

This brief article addresses the question of "What are SIFs, where did they come from, and how do they relate to ASME Section VIII-2 fatigue designs?"

Since B31.3 2007 (and earlier) references finite element methods and ASME Section VIII-2 fatigue methods in Appendices 4 and 5, this is information that should be understood by every senior piping designer.

Markl, FEA, and Div 2. Appendix 5

One benefit of PRG software is the automated calculation of piping stress intensification factors (SIFs). SIFs are automatically calculated in FE-SIF, Nozzle/PRO, and FE/Pipe. In fact, there is no other FEA software in the world that provides automatic SIF calculations.

FE-SIF is specially designed for these calculations and intended to be an “everyday product” for piping engineers to utilize in concert with their usual piping analysis software.

This topic will provide a brief introduction to how SIFs are calculated, how they relate to ASME Section VIII Division 2 fatigue design, and where did SIFs come from.

A Stress Intensification Factor (SIF) is defined as the ratio between the peak stress and average stress in a given component:

SIF = Actual Peak Stress / Nominal Stress in Part

A. R. C. Markl and his team (1950’s) developed the original SIFs still used in ASME piping Codes today.

In his study, Markl determined that girth butt-welds typically resulted in stresses approximately 1.7 to 2.0 times the stress in non-welded piping. As a result, all of the piping codes have been “base lined” to include the factor of 2.0 for girth welds:

$$\text{B31.3 SIF} = \frac{\text{Actual (Peak Stress) due to Moment M}}{\text{Stress in Girth Butt Weld due to Moment M}}$$

OR

$$\text{B31.3 SIF} = \frac{\text{Actual (Peak Stress) due to Moment M}}{2 * \text{(Moment M)} / \text{(Section Modulus Z)}}$$

In terms of ASME Section 8, Division 2, Appendix 5 and finite element analysis (FEA) work, we could use the following equation interchangeably with the previous equations:

$$SIF = \frac{\text{Range of Peak Stress due to M}}{2 * (\text{Moment M}) / (\text{Section Modulus Z})}$$

$$= \frac{2 * (Pl+Pb+Q+F)}{2 * (M / Z)}$$

OR

$$SIF = \frac{\text{Alternating Peak Stress due to M}}{(\text{Moment M}) / (\text{Section Modulus Z})}$$

$$= \frac{(Pl+Pb+Q+F)}{(M / Z)}$$

The peak alternating stress (PL+PB+Q+F) is usually determined from finite element analysis. Normally, the peak stress is the product of the secondary stress and a fatigue strength reduction factor (FSRF). For instance:

$$PL+PB+Q+F = (PL+Pb+Q)*FSRF / 2.0$$

FSRFs are determined from testing or taken from references such as WRC 432.

As discussed in NUREG/CR-3243, the mean curve fitted to Markl’s fatigue test data gives a relationship between the stress range in a butt weld pipe and the number of cycles to cause a thru-wall fatigue failure:

$$i * M / Z = Sf = 490000 * (N)^{-0.20} \text{ (Equation 1)}$$

where

i = stress intensification factor
M = bending moment
Z = section modulus
N = expected number of cycles
Sf = allowable cycling stress

The mean curve described by Equation 1 is shown in the figure below.

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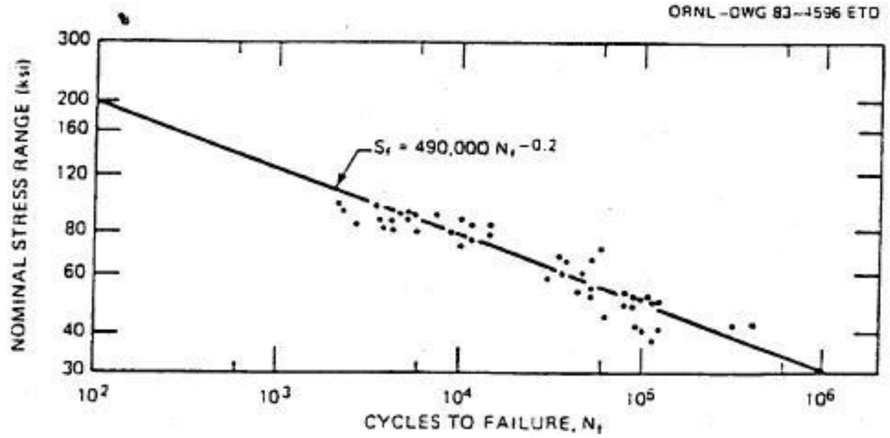

Equation 1 has been normalized based on the peak stress range in a girth butt-weld (i.e. i = 1.0). As a result, there is an inherent factor on the peak stress range "S" of 0.50. All peak stresses given by Markl SIFs are half of their actual values due to Markl's use of girth butt-welds as a baseline.

The factor of two makes the alternating peak stresses used in Division 2 Appendix 4 & 5 very easy to implement in terms of the Markl failure criteria (Equation 1). One could conclude that by using a factor of 0.50 on peak stress, Markl has essentially reduced the stress range to an alternating stress component. Using this conclusion, we can use Division 2 Appendix 4 & 5 peak stresses with the following equation:

$$Pl+Pb+Q+F = 490000 * (N)^{-0.20} \text{ (Equation 2)}$$

$$N = (Pl+Pb+Q+F / 490000)^{-0.20} \text{ (Equation 3)}$$

Equation 2 gives the ASME Section 8, Division 2 alternating peak stress (Pl+Pb+Q+F) that would cause a through-wall fatigue failure with a 50% probability of failure.

Equation 3 gives the number of cycles to failure for a given ASME Section 8, Division 2 alternating peak stress (Pl+Pb+Q+F).

FE-SIF automates these calculations and provides accurate SIFs for all piping components, regardless of their geometry or design.