Tony Paulin, Paulin Research Group, USA, discusses how improved ASME calculations have enhanced safety and reduced risks within the downstream piping industry.

Many plant explosions and accidents can be caused by corrosion, erosion issues, or defects in material. Others are due to operational or maintenance problems. Improving analysis and verification will not eliminate these accidents.

However, the small increased cost associated with improved analysis and verification procedures outlined in this article will minimise overall plant risk associated with overload and stress, while reducing cost associated with layout, changes and unneeded complexity.

**ASME B31 code changes**

This is an interesting time in the evolution of the ASME B31 codes, as some of the recent changes in the approach to the B31 codes calculation of stress intensification factors (SIFs), flexibility factors (k factors) and sustained stress indices (SSIs) hold the potential to significantly impact the safety and economics of future piping designs.

Economic pressure exists today to design, build and operate facilities at a faster pace and at a lower cost. Meanwhile, the safety technologies and experience associated with design, construction and operation are usually slowly developed assets, resulting in an increasing mismatch between objectives and capabilities.

Fortunately, rapidly developing technologies and advances in ASME guidance are keeping pace with many of the economic forces, in order for modern designes, owners and operators to achieve the cost effectiveness required by markets, while simultaneously improving safety and quality.

For example, some manufacturers of piping components (that are far removed from piping design offices, in terms of both distance and fiduciary responsibility) find that they can make parts thinner, thereby reducing the time it takes to make the part and the material costs. Because of their separation from the project, these manufacturers have also found that they can take advantage of the fact that their records are never inspected. The result is a cheaper part, which is often never tested. This lowers costs for all parties involved, but at a lower project safety factor (Figure 1).

Other issues, such as the continued retirement of experienced engineers, the tendency to solicit work from the lowest (least experienced) bidder, and favouring short term profits, further increase the conflict of safety and experience versus profit.

The good news is that ASME code standards (such as B31J, B31H, B16.9 and B31.3), along with new design approaches, are shaping a more effective economic reality for the piping industry and piping fitting businesses, while maintaining a reasonable yet consistent safety factor across all plant components.

**Some simple profound examples**

The following example illustrates just one of the significant corrections to the B31.3 code, provided by B31J, that will eliminate the need for costly large bore pipe rerouting.

**Example 1: significant changes to SIF equations**

The current version of B31.3 (2016) does not include the branch diameter or thickness when calculating the stress intensification factor for an out of plane run moment acting on the branch connection, even though testing from the 1980s shows that SIFs and k factors can be significantly impacted by branch diameter and branch thickness (Figure 2).

The old and new equations can be compared by rearranging the out of plane run pipe SIF expressions from Figure 2 and the latest version of B31J [Table 1].

When \( t/T = 1 \), the ratio of the B31.3 (2016) out of plane run SIF to the 2016 B31J run SIF is shown as a function of \( d/D \) in the plot, as shown in Figure 3.

B31J shows that, as a function of the run pipe diameter to thickness ratio, existing SIFs can be in error by 4 to 12 times. All B1 piping codes permit the use of more applicable data in lieu of Mark’s SIFs and flexibility factors. B31J codifies several well known, but as yet unincorporated, features of branch connections in its ‘more applicable data’.

Some of these guidelines include:

- Out of plane and in plane run SIFs in the 2016 B31.3 code should be reversed.
- For \( D/T=100 \), as the \( d/D \) ratio shrinks, the B31J out of plane run SIF goes to 1.0 and not the current B31.3 SIF of 12.
- For a 24 x 0.375 wall run pipe with a 2 in. small bore branch connection (Figure 4), the out of plane run SIF is nine times the actual value of 1.0. This means that the actual allowed stress using the current B31.3 guidance in the Appendix D of the 2016 edition is only 11% of what the actual allowed stress should be. Experts believe that this has resulted in the unnecessary rerouting of many large bore pipes in both refineries and gas transmission facilities.

**Example 2: k and i factors should consider bend angles**

The current B31 code approach to bends is not yet addressed by B31J, however, Paulin Research Group’s FEATools, in conjunction with Intergraph’s CAESAR II, does address this issue.

Current (and B31J) approaches do not adjust k or i factors as a function of the bend angle, although B31J does make a correction to the k-factor for 90° bends. The difference between the actual k and i factors, and the current B31 code values for a 10 in. pipeline, is shown in Figure 5.

The results in Figure 5 show that current B31 bend k-factors for:

- 90° bends are off by about 20%.
- 45° bends are off by about 33%.
- 22.5° bends are off by about 50%.

Overall calculations of forces and moments in the piping system will correspondingly grow in error as a function of the piping geometry and the ratio of the length of straight pipe to the length of the bends.
Other fundamental design inaccuracies

When evaluating calculation inaccuracies, and as a simplification, the non-conservative error in stress calculations can be taken to be about two. As per A.R.C. Markl, the safety factor for cyclic loadings is also about two. Consequently, at the end of the design life, highly loaded cyclic components in the plant would be about ready to fail due to a thru-wall leak in the pipe.

This indicates the mistake believing that, because a facility has survived for an extended period of time (e.g., 10 years), that the design was adequate. However, failures should not be expected to occur even at the end of the design life, where at least some safety factor should remain.

Putting the responsibility on the owner for inaccuracies in the pipe stress calculation and any failures due to poor maintenance is reasonable, because new issues regarding analysis and fabrication frequently arise. Corrections for these problems should be identified and implemented as quickly as possible, so that critical situations can be addressed before catastrophic failures occur. Fabricators and designers are likely to be well removed from the operating plant when these issues arise. Only the owner may still be involved and invested in the operating plant, and therefore motivated to protect that investment.

More than 30 years ago, when stress analysis was performed using punch cards and mainframe computers, and when plastic models were used to visualise the interaction of steel, pipe, vessels and equipment, only selected lines in simplified configurations were analysed, and generally for only one or two load cases. Today, much more of the piping is analysed, and with a much greater collection of load cases.

The analysis space has evolved into two separate groups of analysis problems (Figure 6). The largest group is comprised of those piping systems that would not have been analysed 30 years ago, but are analysed today. The smaller group is comprised of those systems that would have been analysed 30 years ago and are still analysed today.

The problem is that each group is often analysed using almost identical approaches and technologies. However, the latter group usually comprises the larger, more expensive systems, and most often requires a more accurate analysis approach to produce safer, lower cost designs.

As a result, the overall amount of pipe stress analysis work has increased, while the attention spent on detail has been reduced. In general, the time taken per isometric is limited, and the average experience of the pipe stress designer is lower.

These trends do not have an impact on lines that are analysed and do not need to be, such as:

- Cold, small bore pipe.
- Lines not connected to rotating equipment.
- Lines with relatively low temperatures.
- Lines that do not cycle.

However, this averaged ‘one size fits all’ approach can result in an inadequate analysis of critical piping systems that should otherwise be evaluated more carefully.

New ASME guidelines and inspection technologies can help combat this analysis trend as long as the owner recognises that new guidelines and inspection technologies are available. The owner should only allow automated and low cost analysis alternatives for those systems not exposed to critical load conditions or cyclic service.

An experienced piping designer would know when to apply a more careful and thorough analysis to a piping segment or connection, and should be given the latitude to do so. However, an inexperienced piping designer may miss some of these requirements, letting the computer do the ‘thinking’ while increasing throughput.

With the application of new technology, which requires no additional experience on the part of the designer, all piping systems can be analysed more thoroughly and with almost no additional effort. This software improvement will lead to fewer poorly designed piping systems, and require little to no
additional effort, significantly reducing the lifecycle cost of the piping (design, installation, operation and maintenance). When a critical piping line is identified, it should receive:
- A thorough analysis by an experienced pipe stress analyst.
- Use of the latest tools and technology (that do not complicate the workflow).
- The latest inspection and validation technologies.
- Analysis by independent groups.
- Thorough evaluation of all identified loading conditions including fluid, seismic and wind.

The most prominent features of the new plant design and maintenance space include:
- A rapidly changing B31 piping code environment that keeps pace with multiple inspection, construction and analysis technologies.
- Highly accurate laser scanning by companies such as Leica Geosystems.
- Major updates to 1980s levels of technology in code documents, such as B31J, B31H, B31S, ASME VIII Divisions 1 and 2, API 579/FFS-1 and PCC-1.
- Modern software systems that help users through the incredible varieties of options available in piping, pressure vessel, structural and computer aided design (CAD) software. These systems automate and integrate new technologies with their standard piping design packages, such as CAESAR II, so that users do not have to change their standard approach to the pipe stress problem to significantly improve the quality and accuracy of their designs.

### Conclusion

Below are three suggestions for moving forward with the principle of ‘more applicable data’.

#### Beware of false assumptions

Owners, designers and operators should not assume that because they have not personally witnessed a failure in a plant or refinery due to errors in calculations, that:
- Failures due to those errors have not occurred.
  - Calculation errors are manifested in many ways in an operating facility.
  - The need for unplanned equipment or component repair should be considered a failure.
- Failures are not close to happening.
  - When errors are present, intended safety factors do not exist, and so plants are operating too close to failure limits.
  - Failures due to cyclic calculation errors are expected to occur at the end of life. In this case, the fact the plant has operated for 10 years means very little in terms of lifetime integrity.
- All operating piping systems are alike.
  - Most piping systems have safety factors much larger than theoretically intended. Errors in SIFs and k factors cannot be tolerated in systems whose safety factor is the code intended minimum value of two.
  - Any unknowns or assumptions should be evaluated to determine their effect on the safety factor.

#### Classify all piping systems

Piping systems should be segregated into one of the following two categories:
- Those that are sensitive to design and operating errors (critical load conditions or cyclic service).
- Those that are not.

Most piping systems will not be sensitive to design and operating errors, and thus do not need a rigorous analysis. Current ‘quick through’ approaches used today are adequate for these systems.

#### Perform rigorous analysis when needed

Existing systems that are sensitive to design and operating errors should be reviewed using the latest analysis and inspection technologies to ensure that the intended safety factor exists through the life of the facility. Furthermore, the owner or engineer should not resist this added analysis or inspection, because modern tools and software make this advanced analysis and operating verification much less complex than in the past, and can be applied as part of the normal operating procedure, having essentially no impact on cost.

### References