Addressing Complex Behaviors in LNG and Thin-Wall Piping Systems

How PRG Software Solves Real Engineering Challenges in LNG Design, Operations, and Fitness-for-Service

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1. The LNG Landscape: Why Advanced Analysis Matters

LNG piping systems operate under conditions that push beyond what standard design codes address directly. Cryogenic temperatures, thin-wall stainless steel construction, high diameter-to-thickness (d/t) ratios, and thermal transients all create engineering problems that simplified beam-based methods and code-level assessments cannot fully resolve.

The LNG industry relies heavily on stainless steel piping. This means that common Fitness-for-Service (FFS) approaches, specifically Level 1 and Level 2 type analyses, are often not applicable. The codes and standards that define those assessment levels were developed primarily around carbon steel behavior. When you have stainless steel piping with dents, local thin areas, or thermal damage, you need Level 3 analysis using finite element methods.

PRG's software tools, FEPipe, NozzlePRO, PCLGold, and BOS B31, were built to handle these situations. They give engineers the ability to evaluate piping conditions that codes do not sufficiently cover, and they do it with purpose-built templates and workflows that are faster than general-purpose FEA programs.

2. Industry Trends Driving the Need for Better Tools

The 2025 LNG Export Procurement Trends Survey, conducted in association with the LNG Export NA Conference & Exhibition, paints a clear picture of where the industry is headed. A large majority of project and procurement leaders (96.16%) expect their project pipelines to increase over the next 12 months, with 42.31% expecting a significant increase. No respondents anticipated a decrease.

When asked about their top strategic priority, 42.31% of respondents said driving operational efficiency. This includes both greenfield design work and brownfield design and FFS work. Another 25% pointed to predictive and preventive maintenance, which also falls squarely into the FFS category.

The most telling finding was about barriers. When asked what stands in the way of meeting their strategic priorities, 50% of respondents identified the talent and skillset gap as a top barrier. Talent capacity came in at 46.15%. Combined, talent-related barriers accounted for 96.15% of responses.

For technology investment over the next 12 months, 66.7% of respondents selected engineering and design services as a priority, and 12.5% selected fabrication services.

What this means for PRG: the industry needs tools that allow engineers to perform advanced analysis without requiring deep FEA expertise. It needs training and learning resources. It also needs software that can produce code-compliant results quickly, because the talent pool is stretched thin and the project pipeline is growing.

3. Temperature Differences and Thermal Bowing

Thermal bowing happens when different regions of a pipe wall operate at different temperatures. The typical case is a top-to-bottom temperature difference. One side of the wall stays cold while the opposite side is warmer, and the resulting differential expansion bends the pipe. This effect occurs under both hot and cold operating conditions.

In LNG service, thermal bowing shows up in catch tanks and filling arms where overflow situations create temperature gradients across the pipe cross-section. Part of the pipe wall contacts the cryogenic liquid while the upper portion contacts the gas phase. The temperature difference between those two regions drives the bowing.

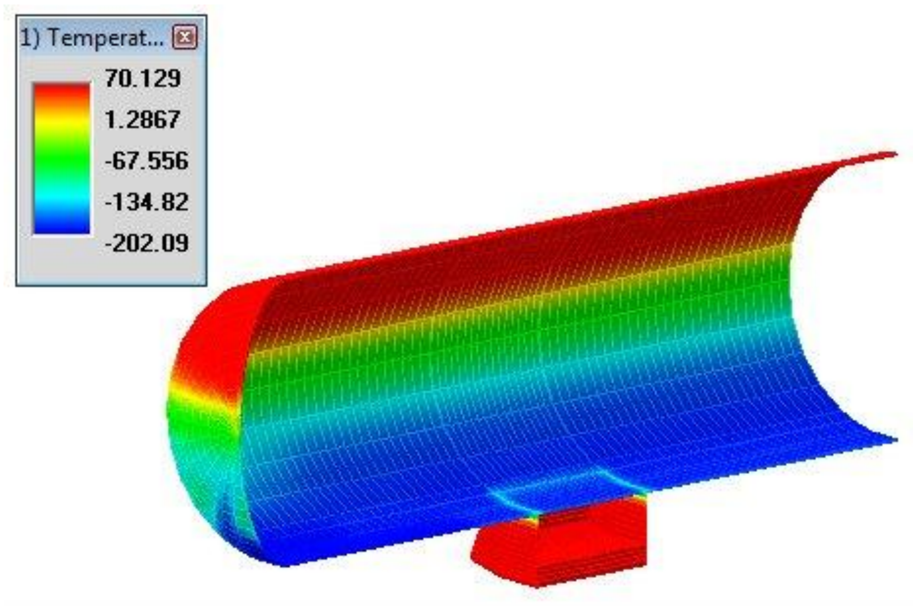

Figure 1: FEPipe temperature contour showing top-to-bottom thermal gradient on a horizontal vessel. The red region at the top represents the warmer gas phase, while the blue region at the bottom represents contact with cryogenic liquid.

In thin-wall piping, where stiffness is already reduced, thermal bowing becomes a critical factor in stress response. It introduces significant secondary loading that simplified methods will overlook.

How PRG software handles this:

FEPipe's axisymmetric template has heat transfer capabilities built in. You can set different parts of the model to have different thermal boundary conditions, one for the liquid part of the LNG and one for the gas part. Both transient and steady-state temperatures can be computed, so you can represent thermal gradients as they develop over time.

PCLGold complements this by allowing you to assign separate top and bottom wall temperatures directly. It then automatically applies an equivalent moment couple to produce the correct bowing response. This gives engineers a straightforward way to model bowing stresses within a pipe stress analysis.

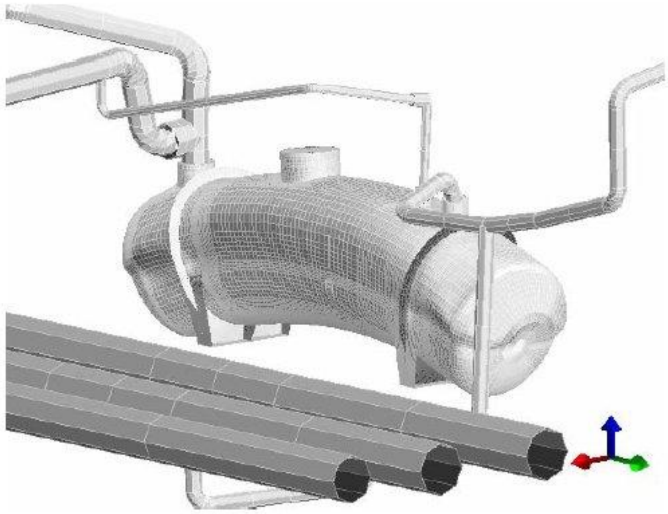

Figure 2: Operating displacements at 50% full. Exaggerated displaced shape plot showing the effect of conservative differential temperature on the catch tank and connected piping.

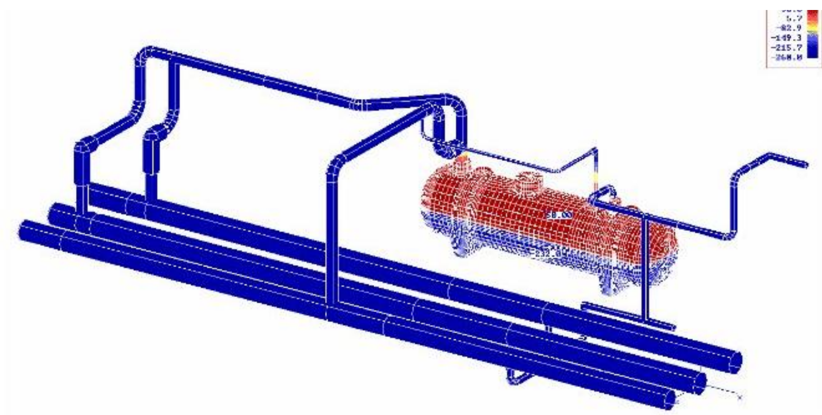

Figure 3: Worst-case assumed thermal profile applied to the full piping system model, showing the catch tank and connected piping with temperature contours from the FEPipe analysis.

4. High D/T Ratios and the Limits of Simplified Methods

As pipe diameters increase in LNG facilities, d/t ratios can exceed 100. At that scale, the assumptions built into code-based simplifications become unreliable. Thin-wall construction also reduces the inherent margin of safety, especially when pipe is ordered to precise thicknesses rather than nominal values.

Beam-based methods work well for routine analysis. In high d/t piping, however, they rely on generalized stress intensification factors and cannot capture all aspects of local behavior. Shell models provide a more detailed representation because they incorporate the actual geometry of the pipe wall. This allows both membrane and bending stresses to be resolved, and it includes ovalization effects that directly influence stiffness and load response.

How PRG software handles this:

FEPipe supports shell-element modeling with nonlinear solvers, so you can evaluate elastic behavior as well as permanent deformation. For high d/t piping, this capability ensures that critical local responses are captured. FEPipe's ability to resolve membrane and bending stresses, ovalization, and permanent deformation makes it well suited for thin-wall piping where simplified methods fall short.

5. Boundary Conditions and Localized Thermal Effects

Code guidance generally assumes uniform thermal conditions. In practice, LNG piping systems often operate with localized heating or boundary conditions that change with time. Regions of pipe may be exposed to evaporation or rapid phase change effects, producing localized thermal stresses.

FEPipe includes evaporation models for boundary conditions. This allows you to simulate LNG, LN2, or any liquid evaporation and flow scenario. By applying fixed temperature conditions and running the plastic solver, engineers can determine whether a lower bound limit load has been reached. This provides a direct way to assess margin in situations where prescriptive methods do not apply.

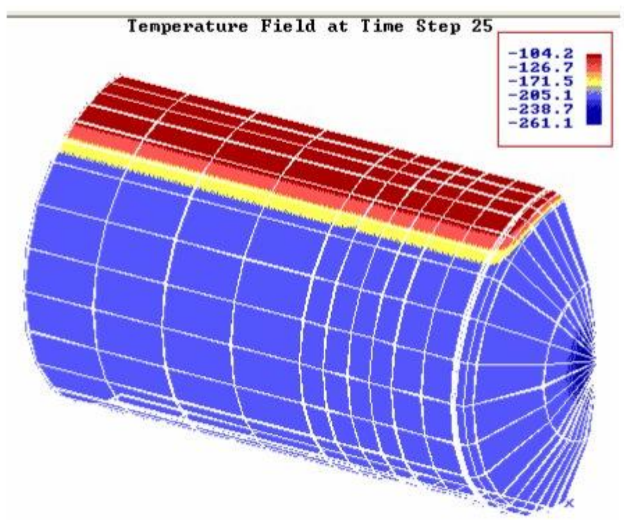

Figure 4: Simplified evaporation model in FEPipe used for validation. Quarter-symmetry model showing the temperature field at a given time step, with the liquid region (blue) and the gas/evaporation region (red/yellow) clearly distinguished.

PRG has used this model for LNG boil-off analysis in overflow tanks and loading arms, which are common scenarios in LNG terminal operations. The thermal profiles through different unloading and fill scenarios can be studied to understand how temperatures develop over time at various locations on the tank and piping.

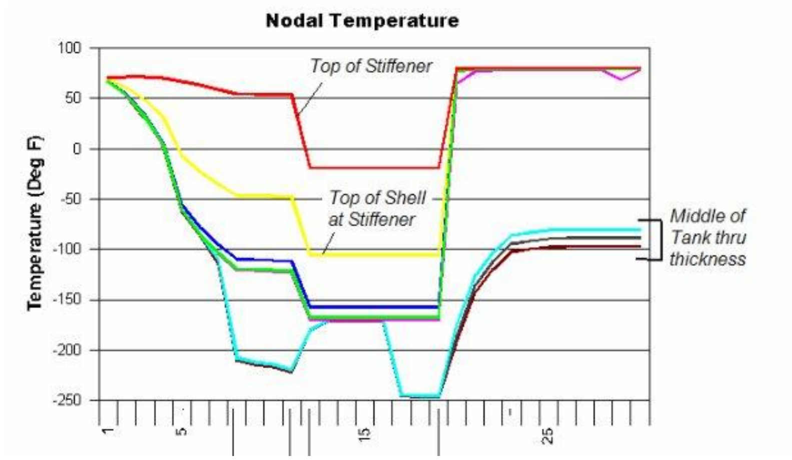

Figure 5: Thermal profile through two unloading processes, showing nodal temperatures at multiple tank locations over time. The evaporation boundary condition and local stress calculations capture the transient thermal behavior during LNG operations.

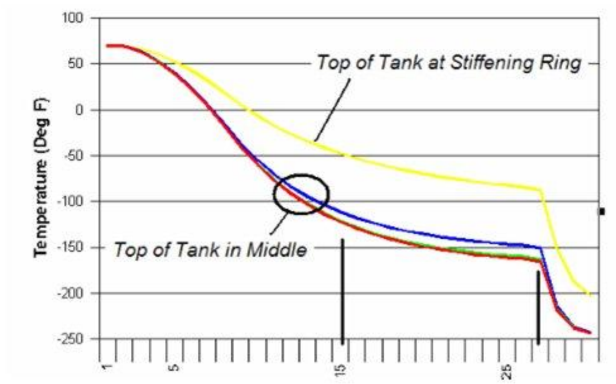

Figure 6: Temperature profile during compressed time scale showing the continued filling of the sump tank. Temperatures at the top of tank at the stiffening ring and at mid-section are plotted over time.

6. Dent Assessment in Thin-Wall Piping

Dents and local deformation are common problems in thin-wall stainless steel piping, and this comes up often in LNG service. The standard FFS approach for dents uses Level 1 and Level 2 methods, but those methods are strictly speaking not applicable to thin-wall stainless steel. The assumptions behind those assessment levels were developed around carbon steel properties and behavior.

When you encounter a dent in stainless steel LNG piping, Level 3 analysis is the path forward. This means nonlinear finite element analysis of the dented geometry to evaluate structural response.

How PRG software handles this:

FEPipe and **NozzlePRO** can both perform Level 3 FFS analysis on dented piping. Nonlinear finite element analysis is applied to evaluate the structural response. NozzlePRO extends this capability to intersections and areas of local damage, providing the resolution needed to assess structural adequacy. Through the Drawing Tools, local thin areas and cracks can be added into the model for Level 3 calculations per API 579/ASME FFS-1.

Users can enter flaw dimensions directly, define them in a spreadsheet grid that auto-calculates critical flaw dimensions, or define the defect on the model graphically.

7. Rapid Heat Flux and Structural Limits

When piping or components are exposed to rapid heat flux, codes may not be sufficient. The standard practice is to estimate heat flux through radiation and convection models, then develop the corresponding temperature profile.

In general, when we have had to deal with rapid heat flux into a mechanical component, we develop a radiation model and a convection model. From those, we determine the heat flux and the developing temperature profile. We use linear heat transfer models for this step. Once we have an estimated temperature of the shell, a manual strength calculation can provide a conservative estimate of the pressure retention capacity.

FEPipe supports linear heat transfer models that handle this. Once a wall temperature distribution is estimated, the plastic solver can be run with fixed temperature conditions to determine whether a lower bound limit load is reached. Manual strength calculations can be used alongside this method as a conservative check. This combined approach has been applied in cases where rapid or localized heating dominates the structural response.

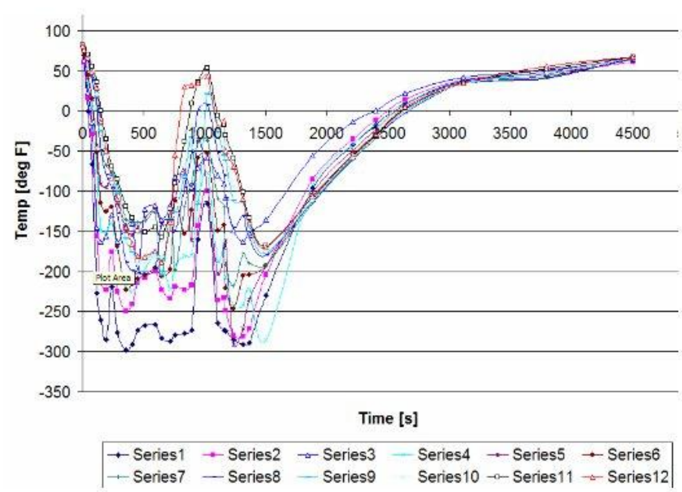

Figure 7: Experimental thermocouple data showing temperature response when water was poured on top of a 3.5-inch pipe half full of liquid nitrogen. This type of physical testing supports validation of the thermal models used in FEPipe.

8. Fluid-Structure Interaction and Valve Closure: BOS B31

Valve closure events produce unbalanced forces in piping systems that must be evaluated. BOS B31 is a frequency domain fluid-structure interaction program that handles a wide range of fluid loading. The key advantage of the frequency domain solution is that it requires very little input or expertise from the user, and it focuses on the mechanical response of the system. Reasonable estimates of the mechanical response are easier to predict than precise fluid responses.

For more sophisticated users, the input can be controlled within the frequency domain solution space to get more detailed results.

Practical guidance for valve closure analysis:

If nothing about the valve is known and a first pass solution must be performed, our recommendation is to take one half of the nominal diameter of the valve in inches as the valve closure time in seconds. When a total valve closure time is known but nothing else, we recommend entering 50% of that closure time. If a more detailed closure profile is available, we recommend that the user plot the curve and take the linear portion at the end of closure as the total valve closure time for computing unbalanced loads.

For a sensitivity study using a known closure time: use 10% of the total closure time as an overestimate of the shortness of closure, and 50% as a likely reasonable estimate of the closure time that produces mechanical-level pressure pulses.

BOS B31 uses the fluid-structure interaction frequency domain analysis to comply with B31.3 loading requirements in Para. 301.5.

9. Fitness-for-Service in LNG Stainless Steel Piping

Fitness-for-Service assessments in LNG piping come up frequently because of the material and operating conditions involved. Stainless steel piping at cryogenic temperatures, with potential dents, local thin areas, or crack-like flaws, often falls outside the scope of Level 1 and Level 2 FFS methods.

FEPipe's FFS program supports API 579/ASME FFS-1 and allows direct entry of flaw or corrosion details. Level 1, Level 2, and Level 3 calculations can all be performed. For Level 3, the Drawing Tools allow local thin areas and cracks to be added directly into the finite element model. The analysis then uses ASME Section VIII Division 2 Part 5 methods for elastic, elastic-perfectly plastic, and elastic-plastic FEA analysis.

NozzlePRO also evaluates flaws or cracks in pressurized or loaded components using Level 3 FFS analysis. Between the two programs, engineers can assess the structural adequacy of damaged piping and components across a wide range of geometries.

The flaw detection capability in both FEPipe and NozzlePRO predicts crack growth for given stress states, helping engineers determine when a crack will reach half-wall or through-wall for leak assessment.

10. FLNG (Floating Liquefied Natural Gas) Applications

FLNG facilities add another layer of complexity to piping analysis. Ship motion introduces acceleration loads that onshore facilities do not experience. FEPipe includes the ability to apply acceleration loads due to ship motion or transportation, which makes it directly applicable to FLNG piping systems.

The same thermal bowing, high d/t ratio, boundary condition, and FFS capabilities described throughout this paper apply to FLNG as well. The difference is that the loading environment includes dynamic motion effects on top of the thermal and pressure loads. FEPipe handles all of these in combination.

11. PRG Software Summary: Which Tool for Which Problem

The table below maps common LNG engineering challenges to the PRG tool best suited for each one.

LNG Challenge	PRG Tool	Capability
Thermal bowing (catch tanks, filling arms)	**FEPipe**	Axisymmetric heat transfer with separate liquid/gas boundary conditions; transient and steady-state
Thermal bowing in pipe stress	**PCLGold**	Top/bottom wall temperatures with automatic moment couple for bowing response
High d/t piping (d/t > 100)	**FEPipe**	Shell-element modeling with nonlinear solvers; membrane, bending, and ovalization
Localized thermal effects, evaporation	**FEPipe**	Evaporation boundary condition models; plastic solver for limit load assessment
Dent assessment (stainless steel)	**FEPipe / NozzlePRO**	Level 3 FFS with nonlinear FEA; API 579/ASME FFS-1 compliance
Rapid heat flux	**FEPipe**	Linear heat transfer models; plastic solver for lower bound limit load
Valve closure / fluid-structure interaction	**BOS B31**	Frequency domain analysis; B31.3 Para. 301.5 compliance
Crack and flaw assessment	**FEPipe / NozzlePRO**	Flaw detection with crack growth prediction; Level 2 and 3 FFS
FLNG ship motion loads	**FEPipe**	Acceleration loads due to ship motion or transportation
Nozzle and intersection analysis	**NozzlePRO**	FEA of nozzles, saddles, pipe shoes on various head types; ASME code reporting
SIF / SSI / k-factor calculation	**FEATools**	FEA-based SIFs, SSIs, and k-factors for branch connections in piping models

12. Conclusion

Thin-wall piping in LNG applications faces challenges that design codes only partially address. Thermal bowing from uneven temperatures, high d/t ratios requiring shell-element analysis, complex boundary conditions with localized heating, local damage such as dents, rapid heat flux, and fluid-structure interaction from valve closures all require analysis methods that go beyond simplified code checks.

The industry survey data reinforces that engineering and design services are where the investment is going. With project pipelines growing and the talent gap as the number one barrier, engineers need tools that are purpose-built for these problems and that produce code-compliant results efficiently.

FEPipe addresses these challenges through shell modeling, heat transfer analysis, and nonlinear limit load assessment. PCLGold provides direct modeling of thermal bowing using top-to-bottom wall temperature inputs. NozzlePRO extends capability to Level 3 Fitness-for-Service of dents and local damage through nonlinear finite element analysis. BOS B31 handles the fluid-structure interaction side for valve closure and unbalanced force analysis.

Together, these tools give engineers methods to evaluate piping conditions that codes do not sufficiently cover, ensuring that critical structural behaviors are examined with the required level of detail.

Learn More

To schedule a consultation or learn more about PRG software for LNG applications:

Request a Consultation: www.paulin.com/request-a-consultation