Improving Gas Pipeline Squeeze-Off Standards with Numerical Simulation

In order to reduce the challenges associated with everyday gas pipeline maintenance, Gas Technology Institute (GTI) uses simulation-driven engineering to propose revisions to the ASTM squeeze-off standards.

by **BRIANNE COSTA**

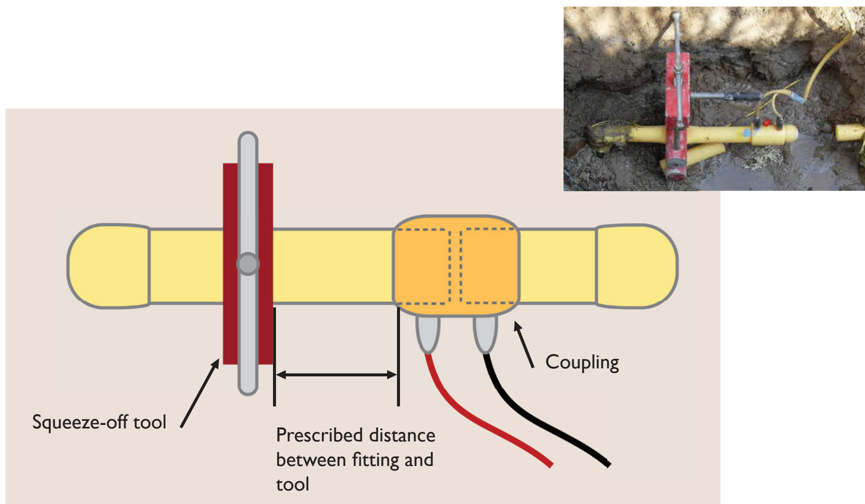


FIGURE 1. A polyethylene gas pipeline undergoing a squeeze-off procedure.

Routine natural gas maintenance procedures often require digging into main roads, forcing drivers to navigate through a complex series of detours and backroads. But what if the process of repairing and replacing gas pipelines could be more efficient and less invasive? Gas Technology Institute (GTI), a leader in natural gas research, development, and training, aimed to investigate the industry standards for squeeze-off length in gas pipelines in an effort to make the pipes more accessible.

⇨ HOW CLOSE CAN YOU SQUEEZE OFF?

Illinois-based GTI is a research and development organization committed to the advancement of new energy and natural gas technologies. One sector of their research involves the investigation of squeeze-off distances for polyethylene (PE) gas pipelines. Squeeze-off is a seemingly simple procedure that involves compressing a pipe to completely stop the flow of gas (see Figure 1). This is commonly performed for maintenance tasks and to replace sections of pipe without shutting down the whole system.

After squeeze-off is completed, the pipe recovers much of its original shape, allowing gas flow to resume. There are natural benefits to polyethylene as a pipe material: its flexibility and ability to undergo large deformations; the absence of corrosion; its fusable and homogenous nature; and its resistance to harsh environmental conditions.

To avoid damage and malfunction, there are certain standards, such as the ones published by the American Society for Testing and Materials (ASTM), which must be met during the squeeze-off procedure. One particular standard involves the location of the squeeze-off relative to pipe fittings. The standard states that squeeze-off must be at a distance of either the length of three pipe diameters or twelve inches from the next pipe fitting, whichever is greater.

This rule was put in place to avoid strain and breakage in pipes. However, a number of gas utilities are interested in shortening the minimum required distance. The twelve-inch distance requirement is high for most pipelines (the majority of pipes used in housing and commercial applications are 2.375 inches in diameter or smaller). This means that although the three-diameter distance would be seven inches, the squeeze-off still has to be performed at the greater distance of twelve inches. The large length requirement for the small pipe diameters leads to more digging into the ground, rerouted roads, and more time and money spent.

> “[We] trust the finite element method implementation in COMSOL for getting good results as proven by previous testing.”
>
> — OREN LEVER, PRINCIPAL ENGINEER, ENERGY DELIVERY & UTILIZATION, GAS TECHNOLOGY INSTITUTE

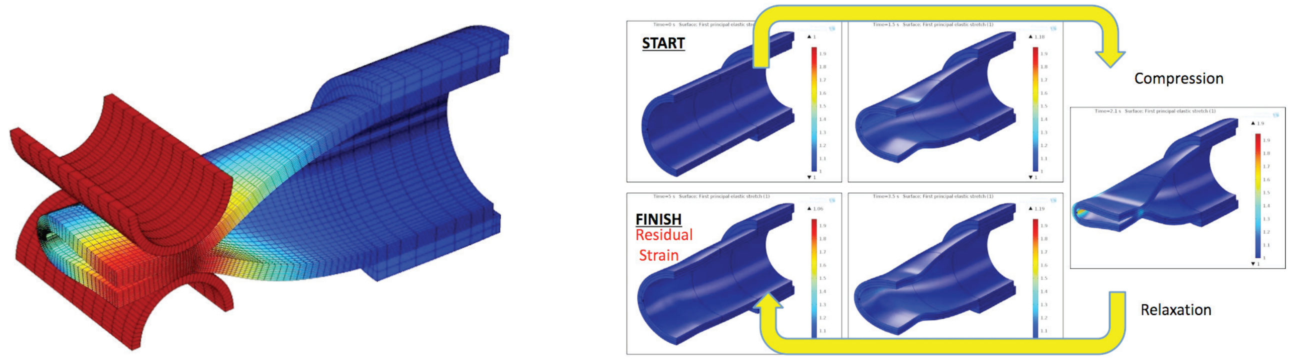


FIGURE 2. A simulation showing the total displacement (mm) of a pipe squeeze-off (left) and the full simulation of the squeeze-off process (right).

Funded by Operations Technology Development (OTD), a technology development partnership of natural gas distribution companies, GTI researchers Oren Lever and Ernest Lever took a closer look to see if the twelve-inch distance is really necessary for smaller pipes. Their goal was to see how close the squeeze-off of the pipe could get to a fused joint before it exceeded industry-accepted levels of strain and increases in stress concentration. To get answers, the team turned to the structural mechanics modeling capabilities of the COMSOL Multiphysics® software.

⇨ STRESS AND STRAIN ANALYSIS OF THE POLYETHYLENE PIPES

The GTI team set up a fully parametric time-dependent model using the Structural Mechanics Module and the Nonlinear Structural Materials Module in COMSOL. As Oren Lever of GTI says, their team "trusts the finite element method implementation in COMSOL® software for getting good results as proven by previous testing." They defined the mechanical and numerical properties of two sets of contacts to model the internal pipe-to-pipe and the external pipe-to-squeeze-off-mechanism structural contact, respectively.

They used the meshing capabilities of the COMSOL software to create a hybrid mesh by integrating structured and unstructured meshes. This approach, together with a custom constitutive model implemented in the software, allowed the team to accurately analyze the large deformations in the pipe. The simulation accounted for the different stages of the squeeze-off procedure shown in Figure 2: pressurization of the pipe, squeeze-off, hold, release, and relaxation.

Special attention had to be given to the meshing of the pipe under the squeeze bars to enable the simulation to analyze the very large deformations encountered when the pipe is fully squeezed off (see Figure 3). Thanks to the meshing capabilities in COMSOL and its parametric nature this particular meshing was easily scaled to different pipe sizes. While the stresses and strains in this region were not the focus of this project, they are of interest regarding the general effect of squeeze-off on the lifetime of the pipe. The COMSOL model will allow the GTI team to conduct further squeeze-off investigations.

⇨ HIGHLY NONLINEAR MATERIALS CALL FOR COLLABORATION

To capture the unique behavior of polyethylene, GTI needed a custom viscoelastic-plastic constitutive model. For this, they turned to Veryst Engineering, a COMSOL Certified Consultant, for help in implementing the chosen material model in COMSOL Multiphysics. To do this, explained Nagi Elabbasi from Veryst, they first selected the experimental material tests needed to calibrate the material law typically used for thermoplastics such as PE, then fit the material parameters to the stress-strain response of PE, and finally implement in COMSOL the set of ordinary differential equations (ODEs) needed for the custom material model.

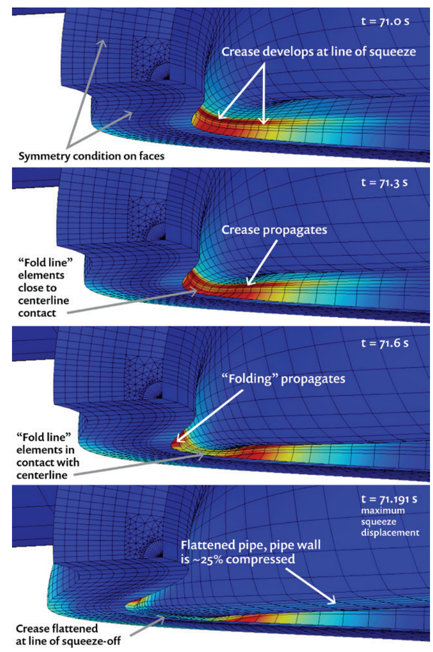
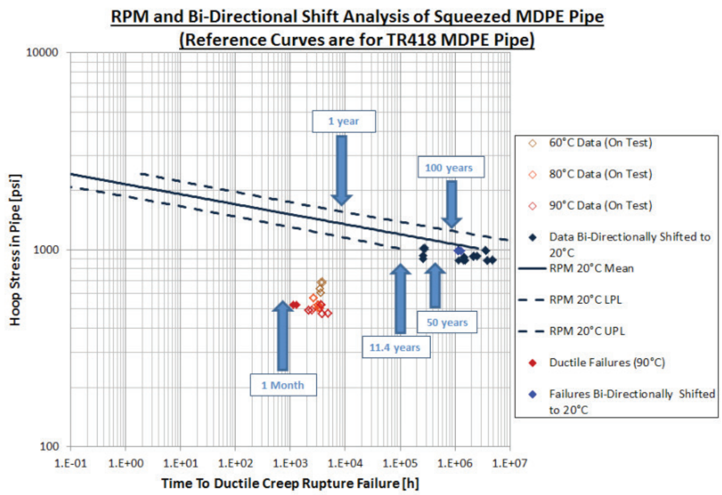


FIGURE 3. Deformation at the line of squeeze-off at different time steps, just before and at maximum squeeze displacement.

The material tests have been carried out by GTI on medium-density polyethylene (MDPE) pipe materials and included tension and compression tests at different temperatures, strain rates, and strains, especially high strains, as well as loading and unloading tests (see Figure 4). The team at Veryst found actual values of material parameters that fit the experimental data. To calibrate, Veryst used MCalibration, an



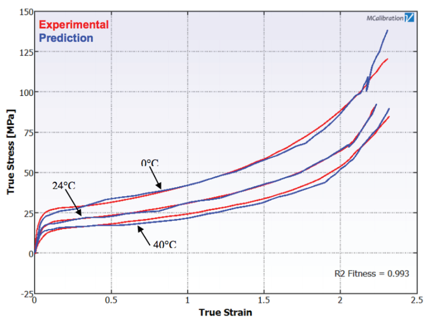


FIGURE 4. Example of the tensile response of PE and the model fit made by Veryst Engineering (bottom) and accelerated lifetime tests for the PE pipe squeeze-off performed by Gas Technology Institute (top).

optimization tool they developed to vary parameters until a very good fit of experimental data is discovered. To implement and verify the calibrated material law in COMSOL Multiphysics, Veryst relied on the software's flexibility by adding a system of ODEs representing additional states used to describe the custom constitutive model.

Another option, useful in those cases where a material model cannot be described by equations, would have been to use the External Material feature to access functions written in FORTRAN or C code and compile them into a shared library. In that case, the external material can be defined by the stress-strain relation, simply return an inelastic strain contribution to the material model in use, or link directly to a commercial external material library like PolyUMod® library from Veryst Engineering.

With simulation, GTI was able to determine that in the case of small-diameter pipes (smaller than 3.5”) the closer squeeze-off distance of three pipe diameters did not cause strains over current industry-accepted strain limits.

They used additional accelerated lifetime testing (shown in Figure 4) to validate these results. Squeeze-off was tested at two and four inches from the fused coupling at temperatures high enough to accelerate the creep rate in the polyethylene when compared to normal operation. Through this extra testing, the team at GTI discovered that the pipes would have an 80-year lifetime when operating at an average temperature of 20°C. This agrees with the standard industry lifetime of 80 years for MDPE gas pipelines.

➾ EFFICIENCY IS KEY FOR FUTURE PLANS AT GTI

From their simulation work, GTI found that the squeeze-off location on small diameter pipes can be closer to the fitting than the current minimum distance allowed under the ASTM standard. This confirms that the current twelve-inch minimum distance requirement can be reevaluated for smaller pipe diameters, which are the most commonly used sizes for residential and commercial gas applications. Thanks to their research, GTI is helping set new guidelines that will make the current gas pipeline maintenance process less expensive, more efficient, and less invasive.

Ernest Lever, R&D director (left) and Oren Lever, principal engineer (right) at GTI.

Regarding plans for further research, Lever says their team plans to expand the constitutive model to include temperature and creep in order to describe relaxation effects more accurately. The goal is to be able to perform damage propagation and failure analysis to predict the behavior of the pipe for different load scenarios, such as the installation of reinforcement clamps.

GTI will also look into making their findings available to engineers not necessarily versed in numerical simulation. As COMSOL users they have access to the Application Builder, a tool that allows simulation specialists such as Lever to wrap a COMSOL model in a custom user-friendly interface. This means that engineers on the field and maintenance staff involved don't have to second-guess their choices, especially in unusual operating scenarios. Meanwhile, simulation specialists save time and can focus on a new project. For now, GTI continues to devote their research and development efforts to natural gas and energy innovations. ❖