Field Tests of TR650 Squeeze-off Tool Successful

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Timberline's TR650 squeeze-off tool or above-ground repair of polyethylene pipe between 3-in. and 6-in. diameter is commercially available following successful completion of laboratory and field tests.

Natural gas is a widely used, clean and efficient fuel, and its consumption is growing (Figure 1). Natural gas utilities operate and maintain more than 1.2 million miles of underground pipes for delivery of natural gas, according to reports by the American Gas Association. Polyethylene (PE) pipe constitutes the majority of gas distribution piping installed in the United States today.

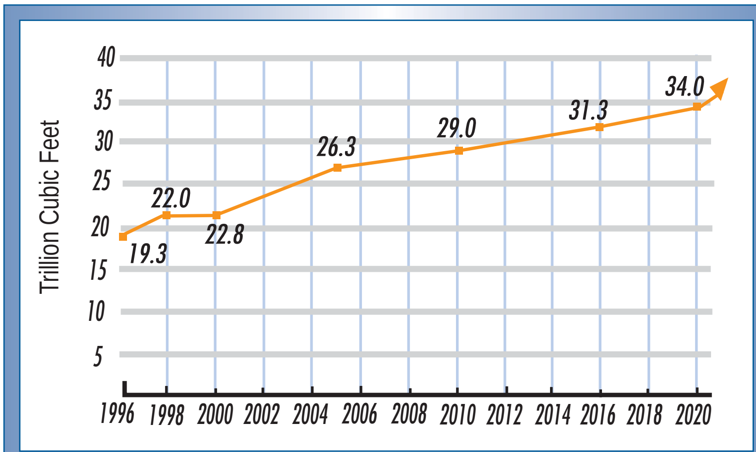

Figure 1. U. S. Department of Transportation forecasts a 50% increase in natural gas consumption by 2020.

The U.S. Department of Transportation forecasts a 50% increase in the demand for natural gas by 2020. It is important to maintain the existing and growing infrastructure to ensure the safe and reliable delivery of natural gas in the future.

The report titled *Natural Gas Infrastructure Reliability—Pathways for Enhanced Integrity, Reliability and Deliverability*, developed by the U. S. Department of Energy/Office of Fossil Energy and the National Energy Technology Laboratory, draws attention to the need for improved tools for the construction, maintenance and repair of the gas pipe that makes up the majority of America's natural gas distribution network. This report cites a preference for cost-effective and efficient tools to facilitate repair through "keyhole" excavation access, providing significant safety and cost advantages over backhoe-style excavations. With the financial assistance of the Department of Energy through a Small Business Innovation Research Award and cost-sharing support from natural gas industry companies, Timberline Tool was able to develop its TR650 specifically designed for repairing large-diameter plastic pipe in keyhole situations.

Similar to arthroscopic surgery, keyhole access technology allows the buried natural gas pipe to be accessed and squeezed-off or repaired through a small (18-in. diameter) keyhole above the pipe. It eliminates the need for extensive and disruptive excavation with a backhoe or other large equipment at the repair site (Figure 2).

Timely repair of a leaking natural gas pipeline is of critical importance to the safety, reliability and cost effectiveness of the United States' natural gas pipeline system. The important first step in any gas line repair is to stop the flow of natural gas. Squeeze-off is a procedure used to temporarily shut-off the flow of gas in the pipeline to facilitate maintenance or repair operations. During the squeeze-off procedure, the pipe is compressed between two bars until the flow of gas within the pipe stops. After the maintenance or repair to the gas line has been completed, the bars are released and gas flow through the line resumes. In June 2002, Timberline Tool began to develop a mechanical tool to squeeze-off between 3-in. and 6-in. PE pipe using keyhole technology (Figure 3).

Squeeze-off tools are available for use on smaller natural gas pipes (between a half-in. and 2-in.) for traditional and keyhole excavations. However, squeeze-off tools for repair of larger gas pipes (between 3-in. and 6-in.) through 18-in. keyhole access were not available until the recent development of Timberline's TR650, which enabled squeeze-off to be performed from the top-down, in one simple operation. By squeezing-off PE pipe from the top-down, substantial time and labor costs associated with extensive excavation are reduced.

Recent field evaluations of the tool at several natural gas companies (Figure 4) demonstrate advantages over traditional squeeze-off tools for natural gas between pipe 3-in. and 6-in. The tool's new design is lightweight, a single operator can manage it, and it and keeps workers out of the trench.

KeySpan Energy and NW Natural estimate the tool will generate savings per excavation of more than $1,000 compared with traditional excavations. Each of these companies performs between 500 and 1,100 squeeze-offs in their territory per year.

"Our existing keyhole program for service installation and main inspection has been successful, but this type of tool will expand our capabilities tremendously," said George Gent, NW Natural's manager of construction and technical services.

During Phase 1, the feasibility of the TR650 was demonstrated successfully to utilities cited in Figure 4. This new keyhole squeeze-off tool concept for PE pipe between 3-in. and 6-in. is a natural fit for Timberline Tool's product line, which includes TopReach squeeze-off tools in use for PE pipe between a half-in. and 2-in. for access holes as small as 18-in. in diameter.

Significant research and development in Phase 2 provided optimal design characteristics and operational procedures for the engineered prototype. The approach in both phases included detailed engineering analyses, and rigorous and carefully controlled laboratory tests and field tests in preparation for commercialization.

The anticipated public benefits include safety of workers and neighborhoods, reliable squeeze-off and cost effectiveness. The tool's remote operation keeps the worker out of the trench and away from blowing gas, and operates through keyhole access without the need for large excavations. Operators are able to perform the repair work more quickly and in smaller areas decreasing the chance of danger to themselves and others in the area. The tool is built from high strength, non-sparking aluminum alloy.

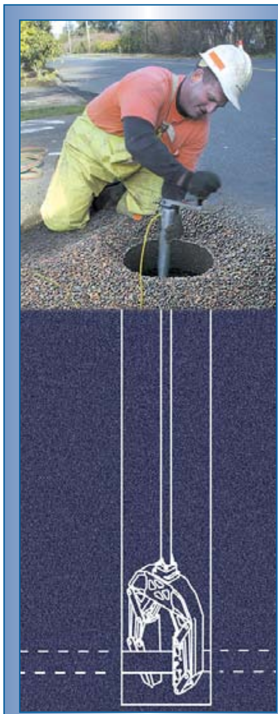

Figure 2. Timberline's "keyhole" solution for PE pipe repair.

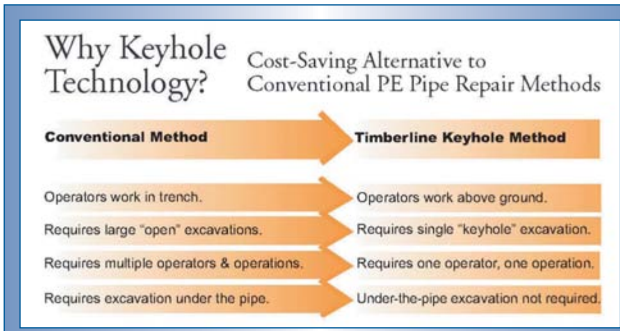

Figure 3. Keyhole technology increases safety, saves labor and time and provides significant cost savings.

Company	Location
NW Natural	Portland, OR
Sempra Energy Utility	San Diego & Los Angeles , CA
Questar Gas Company	Salt Lake City, UT
Southwest Gas Corporation	Tempe, AZ & Las Vegas, NV
Nicor Gas	Naperville, FL
DTE Energy (MichCon)	Melvindale, MI
KeySpan Energy Delivery	Hicksville, NY
Oregon State University	Corvallis, OR

Figure 4. Natural gas companies participating in the field evaluations of Timberline's TR650.

The new squeeze-off tool demonstrated reliable squeeze-off when field-tested by partners on PE pipe between 3-in. and 6-in. diameter. Utility operators were consistently able to squeeze-off the pipe without inducing damage. The tool was designed and built to apply limited pipe compression so it cannot over-squeeze the pipe; operators can control the squeeze-off and release rate preventing pipe damage. The squeeze tool geometry, such as 4-in. squeeze bar radius, enables reliable squeeze-off with less pipe compression.

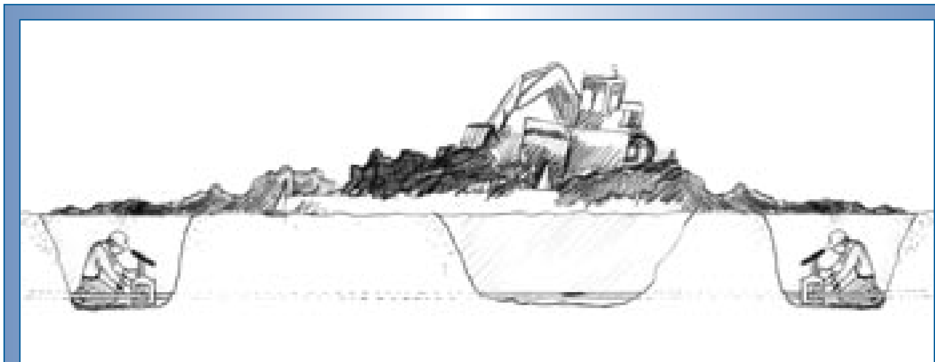

Figure 5. Conventional method for repairing large-diameter distribution lines.

The tool is designed to automatically center the pipe in the jaws, eliminating visual guidance or other means to ensure proper positioning for a safe squeeze-off. The screw actuating mechanism in the tool prevents uncontrolled quick release that could damage the PE pipe.

Current procedures for repairing buried natural gas pipe are time consuming and expensive. The TR650 squeeze-off tool operates through keyhole access and provides cost savings by reducing squeeze-off time, reducing the size of the excavation required for squeeze-off, reducing the pavement restoration effort, increasing productivity with a single operator performing the repair, and increasing the efficiency of the overall squeeze-off and repair process, which will result in less labor hours and unaccountable gas loss.

This project resulted in a mechanical squeeze-off tool that will substantially lower the time and cost of repairing gas distribution piping between 3-in. and 6-in. diameter. This

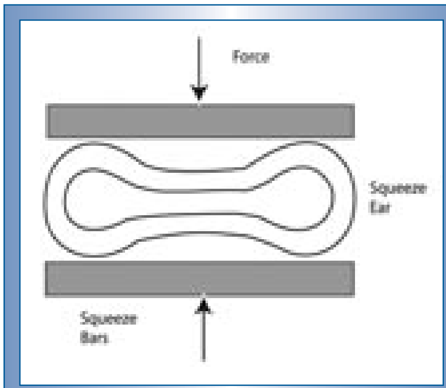

Figure 6. Definition of wall compression.

shows substantial cost savings when using keyhole repair compared with the current operating procedures that require backhoe excavations and heavy equipment to perform the repairs (Figure 5).

The successful demonstrations of the keyhole squeeze-off tool at natural gas utility test sites, the enthusiastic response of utility representatives, and the supporting laboratory tests and analyses provided evidence for technical feasibility. Initial research for this new technology centered on determining the optimum squeeze bar configuration. When PE pipe is being repaired, it is squeezed to prevent gas leakage. Tests were performed to determine the amount of force required to bring the pipe to different degrees of compression with varying parameters such as temperature, squeeze rate and jaw size. Percent compression is defined by the following equation in ASTM F1734-96 (Figure 6).

% Compression = (1-L/2t)

Where *L* = Jaw gap and *t* = average wall thickness expressed in the same units as *L*.

MDPE 2406 SDR 11.5 gas pipe samples were tested in steel jaw fixtures placed in a MTS hydraulic testing frame. A 150,000-lb capacity strain gauge was placed between the hydraulic cylinder and the connection to the top jaw. The bottom jaw was stationary on the blocks placed on the framework table, and the deflection measurements were made in the head of the hydraulic unit. In most cases, two identical runs were made with two different pipe samples. MDPE pipe samples were 2ft and 3ft long for the 4-in. and 6-in. pipe diameters. Pipe samples were temperature equilibrated for at least 24 hours prior to testing.

Steel jaw assemblies were made with 2½-in., 3½-in. and 4½-in. jaws. All jaw major profiles were 4-in. radius, while the edge radius was one-quarter-in. with the exception of early 2½-in. jaw runs where the edge radius was 0.06-in. The 2½-in. jaw was of a fixed design only while the 3½-in. and 4½-in. jaws were used in a fixed and swivel configuration.

The force and deflection data gathered for each run was inspected to find the "linear" region once wall contact was achieved. The force range typically used was between 12,000 lb and 34,000 lb for the 4-in. pipe while between 18,000 lb and 34,000 lb were used for the 6-in. pipe. Second order polynomials were fitted to these ranges for each run. To account for the deflection of the test frame and the jaws, a run was made for each configuration (with no pipe samples) to find the force/deflection values for the entire range (between 800 lb and 36,000 lb). This structural deflection data also was fit to a polynomial.

Duplicate runs were compared and all were reasonably consistent. To calculate the force required to squeeze the pipe to 5%, 10%, 15% and 20%, the equations of any duplicate runs were averaged and the equation for the amount of deflection was subtracted. The resulting new equation was used to generate "true" deflection data for between the 12,000-lb and 40,000-lb force range for each jaw configuration and pipe size. Once again, this data was fit to a polynomial. These final equations were used to calculate the 5%, 10%, 15% and 20% values that are plotted on the 68.7°F 4-in. and 6-in. pipe graphs (figures 7 and 8).

Increasing the jaw width results in a less vertical incline on the wall compression curves. Initially, more force is required to squeeze the pipe until both walls touch. At this point, the force required to compress the walls lessens.

Once the optimum squeeze bar configuration was determined, various conceptual tool designs were developed to accommodate the squeeze bars and incorporate the following design criteria:

- direct approach from above the pipe;
- parallel clamping motion;
- controlled rate of closure and release;
- manual one-person operation;

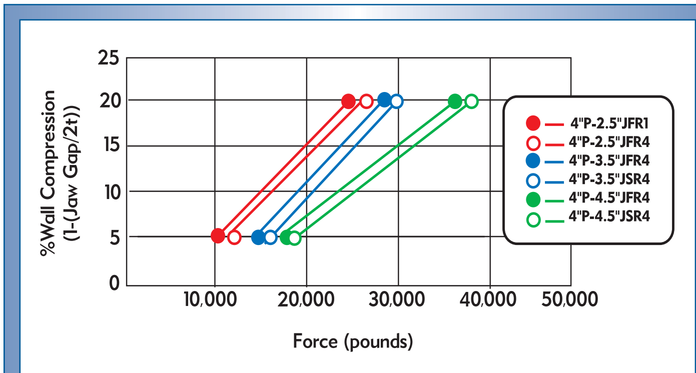

Figure 7. Force required to achieve desired percentage of wall compression for 4-in. MDPE pipe at 68.7°F.

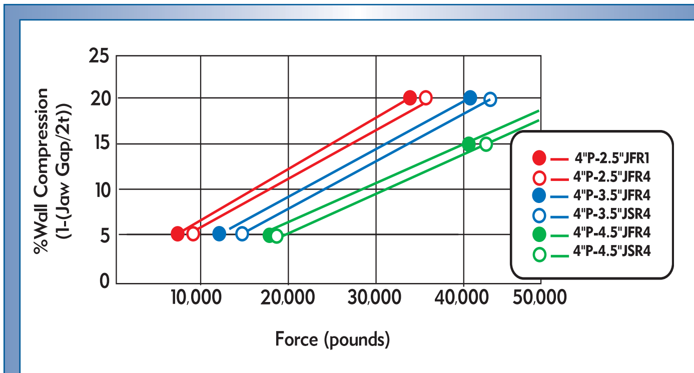

Figure 8. Force required to achieve desired percentage of wall compression for 6-in. MDPE pipe at 68.7°F.

- stop the flow of gas without pipe damage;
- multiple pipe sizes on one tool;
- ability to withstand the forces generated during squeeze-off;
- lightweight and portable; and
- accommodates “lockout/tagout.”

The double actuated design (Figure 9) was preferred over other concepts because both jaws are actuated at the same time, producing only horizontal motion relative to each other. The only sliding part of the tool is the actuator, which is contained within the frame, reducing its exposure to contaminate.

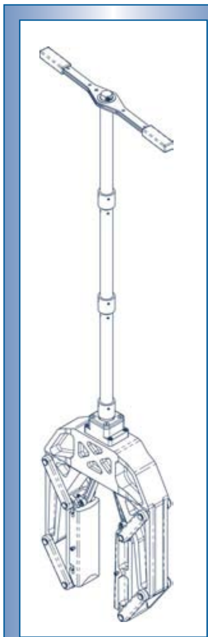

Figure 9. Preferred double-actuated design concept for achieving squeeze-off of between 3-in. and 6-in. PE pipe.

Figure 10. Computer model of the Timberline TR650 yoke.

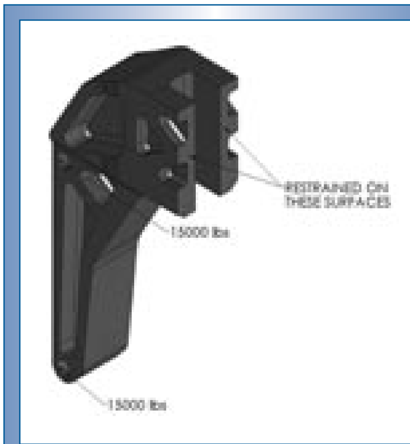

Figure 11. Symmetry of the TR650 yoke simplifies numerical solution.

The yoke (Figure 10) is constructed from a single piece of 4-in.- thick 7075-T6 aluminum and designed to provide up to 30,000 lb of crushing force to a 6-in. PE pipe without suffering deformation. Cosmos software was used for performing the stress analysis on the yoke. Figure 11 shows how symmetry allows half of the yoke to be modeled to simplify the numerical solution. A free-body diagram of the jaws in the closed clamp position shows the 30,000-lb crush force will always divide equally between the top and bottom pins on the yoke. Thus, a 15,000-lb load was applied horizontally to each hole in the yoke. The two surfaces at the plane of symmetry are restrained by material on the other half of the yoke. The high stress concentration areas in the yoke are predictably in the fillets on the inside of the yoke (Figure 12). Dividing the yield stress by the maximum stress in the part (73,000/ 57660) gives a 1.266 safety factor for the yoke when manufactured from 7075-T6 Aluminum.

Figure 13a shows the exaggerated shape of the yoke under load. Since the model is only half of the yoke, the actual measured deflection across the tips of the yoke is double the 0.460-in. This prediction has been correlated to actual measured deflections across the tips when squeeze-off was achieved on a 6-in. pipe. This deflection will be in the elastic range and will return to zero when the clamping load is released.

Following completion of the computer modeling for the components of the TR650, nine engineered prototype tools were manufactured with interchangeable jaws, which permit use of the same tool on PE pipe between 3-in. to 6-in. diameter. These tools are being field tested and evaluated by natural gas companies in various geographic locations. They are being tested for functionality, ease of use and ergonomics. In addition to the functionality tests performed on the prototype delivered to Oregon State University (OSU), sections of the pipe squeezed-off during natural gas company testing were sent to OSU for evaluation of operability in general accordance with *ASTM F1563-01, Standard Specification for Tools to Squeeze-off Polyethylene (PE) Gas Pipe or Tubing*, and *ASTM F1734-96 Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-off Procedure to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe*.

Three specimens each of 4-in. and 6-in. diameter PE pipe were prepared, squeezed and held for 30 minutes. The rate of leakage, if any, was determined using a calibrated rotameter (flowmeter) with 100psi nitrogen supplied to the specimen. Various dimensions were obtained during the procedure.

In addition to inspection procedure within ASTM F1734, the interior and exterior surfaces of the pipe were inspected using scanning electron microscopy at the squeeze ear locations (drop-shaped areas of the pipe created as the walls of the pipe are compressed toward each other).

The remaining specimens were non-destructively inspected on the exterior only. The two remaining 6-in. specimens and one of the remaining 4-in. specimens were then pressure tested.

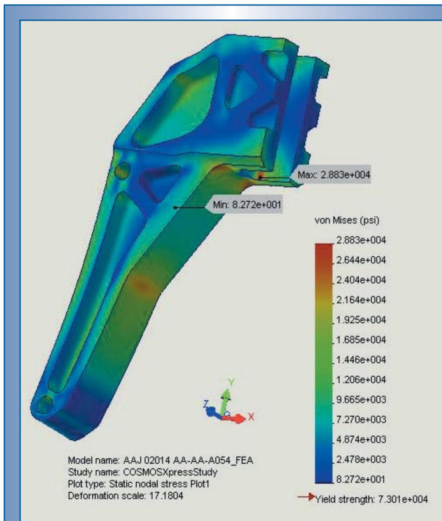

Figure 12. Cosmos computer solution of TR650 yoke under stress.

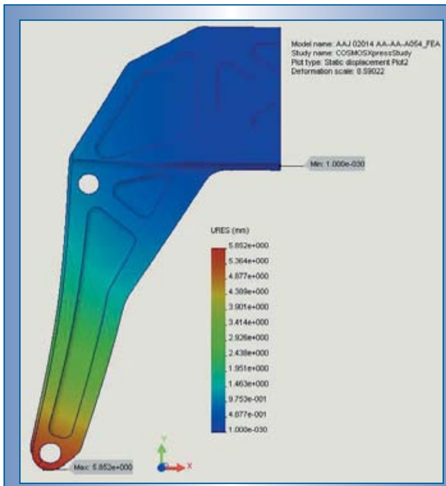

Figure 13a. Cosmos computer solution of TR650 yoke under extreme stress.

Figure 13b. Successful laboratory testing of TR650 on 4-in. MDPE pipe according to ASTM F1563, the standard specification for tools to squeeze-off PE gas pipe or tubing.

The results of testing to ASTM standards are summarized below.

ASTM F1563 Testing—The squeeze-off tool was evaluated for release protection, release rate, flow control, grounding, squeeze-bar configuration, over-squeeze protection and squeeze bar spacing. Evaluations showed the force could only be released by unscrewing the tool. The operator controls the rate of release manually. The tool has a specific location and attachment for grounding. The 4-in. radius squeeze bar exceeds the minimum 1-in. specification. The actual squeeze percentages (wall compression) were significantly less than specifications. The lengths of the squeeze bars were sufficiently long enough to squeeze-off between 4-in. and 6-in. pipe (Figure 13b).

ASTM F1734 Testing—All squeezed specimens subsequently pressure tested and microscopically tested were inspected per ASTM F1734. There was no evidence of a dimple present on the exterior surface of the squeeze ears. A dimple is a slight indentation or depression in the wall of the PE pipe indicative of serious interior cracking. After sectioning to expose the interior surface of the squeeze and visually inspecting, there was no evidence of stress whitening, crazing or cracking. Some wrinkling was present on the interior surface of the squeeze ears. Some wrinkling and stress whitening is expected to occur, according to ASTM F1734.

Additionally, the interior squeeze ear surfaces were inspected using optical stereo microscopy at 10X magnification, and no evidence of cracking or voids was found. There was no evidence of stress whitening present when inspected at magnifications up to 10X. There also was no evidence of changes in color. After these inspections were performed, the squeeze ear was cross-sectioned and inspected for the presence of subsurface voids in the squeeze area and none were found.

The results of these tests confirmed the effectiveness of the TR650 to squeeze-off between 3-in. and 6-in. PE pipe without changing its integrity. The tests at OSU showed complete squeeze-off occurred at about 5% compression, well below the test tool design value of 15%.

The project team designed, constructed and tested the TR650 squeeze-off tool for large-diameter PE pipe (Figure 14). This tool met or exceeded all of the performance goals. Field evaluation and testing demonstrated the feasibility of using the new squeeze-off tool to effectively squeeze-off between 3-in. and 6-in. PE pipe in keyhole situations without damaging it. The natural gas industry personnel's response to participate in this keyhole squeeze-off tool project further demonstrates its success.

"There is absolutely a strong need for this in the field," said Don Brost, a construction quality assurance supervisor at Northwest Natural. "This is the best we've found of its kind." ✧

Acknowledgements

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Figure 14. Pipe integrity maintained following squeezed-off on 6-in. MDPE pipe with the Timberline TR650.