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Fiber optic "trip wire" monitors digging over chemical pipe line

Pressure analysis software, warning tape, and concrete coating also manage risk on new system

Brian L. Payne, P.E., EDM Services, Inc., Simi Valley, California

A recently developed fiber optic "trip wire" * that alerts operators to third-party digging is among a suite of risk-mitigation measures installed on a new hazardous liquid pipe line.

The 7.0-mi, 6.625-in. OD pipe line transports liquid chlorine. Before construction, the operating company insisted on a thorough assessment of the associated risks. EDM Services, Inc., Simi Valley, California, and Jacobs Engineering Group (JEG), Baton Rouge, Louisiana, conducted the assessment.

The EDM/JEG engineering team reviewed all possible pipe line risks, including incident likelihood, severity, and impact. The team then identified and targeted risks associated with this particular line, and reviewed all relevant mitigation measures.

It was concluded that the new trip wire and leak detection software would be used. So too were traditional mitigation measures such as concrete coating and line markers.

With this approach, risk of third-party damage has been minimized, and danger of pipe line damage or product spill reduced.

Since early 1999, when the line was placed in service, there has been no third-party damage, nor leak or spill incidents.

Regulations. Title 49, Code of Federal Regulations, Parts 192 and 195 prescribe the minimum regulatory requirements for natural gas and hazardous liquid pipe lines, respectively. These regulations do not specifically apply to many chemical pipe lines. Nevertheless, for safety, these regulations were incorporated into project design and construction.

In addition, the chemical company decided to employ measures which exceeded these minimum requirements to minimize the possibility and impact of potential spills and leaks.

In designing this pipe line, the potential impacts were characterized by their magnitude (severity of consequences), and anticipated occurrence frequency. Then, mitigation measures were evaluated to minimize event likelihood and severity.

Five steps were taken to assess the risk of upset, and its impact on safety. They included:

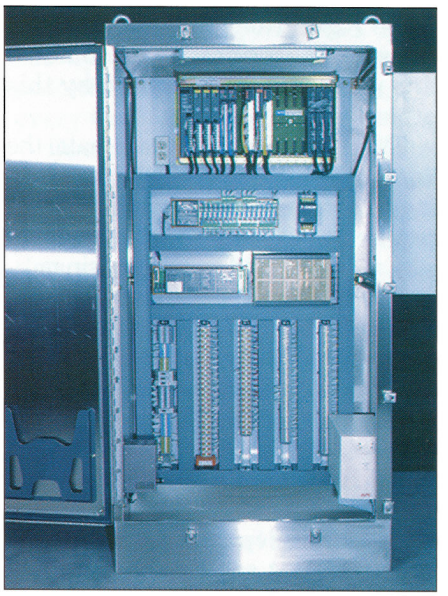
- Developing a range of potential hazards
- Estimating likelihood of hazard occurrence
- Approximating hazard consequences
- Evaluating risk significance based on occurrence probability and consequence severity
- Developing mitigation measures to minimize major risks.

During the potential-impact review, the design team evaluated a variety of pipe line safety data. Available data from the U.S. Department of Transportation's (DOT) Office of Pipeline Safety indicates that natural gas and hazardous liquid pipe line spills are caused by:

- Third parties (outside force)
- External corrosion
- Other causes, including internal corrosion, design flaws, pipe failures, weld failures, and operator error.

Impacts associated with pipe line leaks can be minimized by:

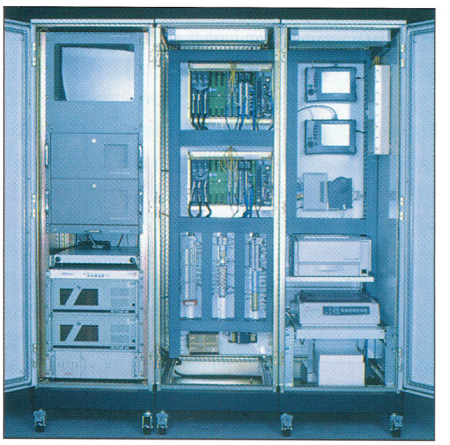
- Reducing occurrence frequency
- Minimizing spill volumes
- Improving emergency response.



PLC. Optical instruments are integrated into the pipe line's PLC/SCADA system, and used to continuously monitor trip wire cable integrity. Moisture analyzers were installed on the line to monitor for the presence of water. These instruments were connected to the SCADA system via the PLCs. Stainless steel enclosures were used to protect the PLCs against the corrosive environment.

Damage. Third-party damage (outside force) is a major cause of natural gas and hazardous liquid pipe line spills. DOT data indicate that roughly one-third of all reported pipe line incidents are caused by third-party damage.

There are several effective miti-



Host. This larger enclosure houses the redundant PLCs, leak detection hardware, trip wire controllers, and other equipment. A separate controller screen was located on the control console.

* TripWire - Patent Pending

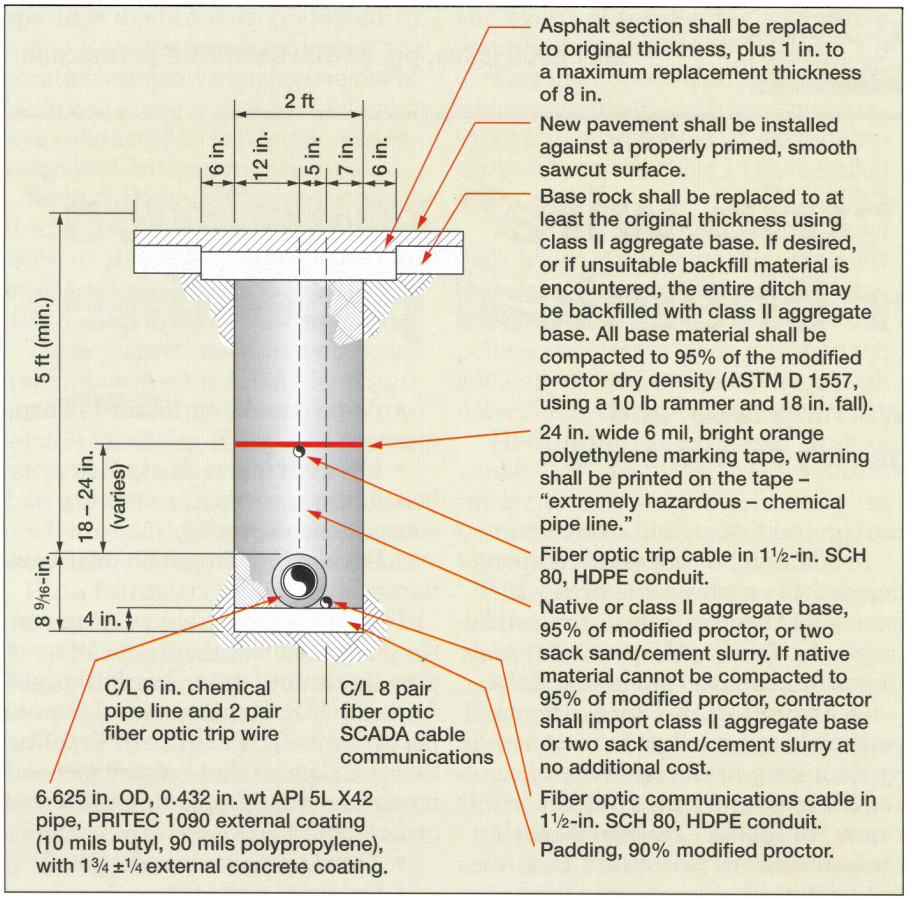


Fig. 1. Cross-section of typical trench section depicting numerous safety measures employed for the hazardous material pipe line.

gation measures to reduce spills caused by third-party damage. Those employed on this project included:

One-call. Every state except Hawaii and the District of Columbia has an underground facility damage prevention law governing the activities of operators and excavators. All but seven states (Connecticut, Iowa, Massachusetts, Maryland, Maine, New Hampshire, and Vermont) have granted exceptions to a variety of organizations.

In general, exempt organizations are not required to participate in a state excavation damage prevention program. Exemptions have been granted to state transportation departments, railroads, mining operations, and governments at the city, state, and federal levels. Exemptions also have been granted to land areas, such as cemeteries, military bases, and Native American lands.

The state where this line was installed has a one-call system. Under the program, excavators are required to mark the boundaries of their proposed excavation and notify the system at least 48 hours prior to excavating.

As per the program, substructure owners within the construction area were notified. They were required to mark their facilities within the area to prevent construction-related damage. To date, these one-call services have been effective in reducing such third-party damage.

Markers. Although line markers are required by 49 CFR 192 and 195, those regulations also require project-specific specifications. Additional line markers were required by this project's specifications.

These additional markers make the line more visible to third parties working in the area. Line markers were required on each side of all road, highway, railroad, and water crossings.

Intermediate line markers also were required, such that at least two markers were visible from any location along the line. Aerial line markers were specified to provide markings for periodic aerial right-of-way inspections.

All line markers were labeled with the pipe line operator's 24-hr emergency telephone number.

Tape. As a secondary means of third-party damage protection, a polyethylene marker tape was installed approximately 18 to 24 in. beneath the ground surface, about two feet above the pipe line.

The tape was 24-in. wide by 6 mils thick. The brightly colored marker tape was labeled "Extremely Hazardous—Liquid Pipe Line."

In the event that an excavator disregarded the one-call system and the above grade line markers, he would likely hit the marker tape before damaging the pipe line.

Trip wire. A third level of protection, a proprietary fiber optic trip wire system, also was installed.

This system, developed by EDM Services, provides an advance warning of third-party intrusions which could impact critical buried facilities. It also provides an accurate intrusion location.

The system consists of a fiber optic cable, buried above the pipe line, and just beneath the marker tape (Fig. 1). Optical instruments, integrated into the pipe line's SCADA system, are used to continuously monitor cable integrity.

Should the cable be damaged or severed, the optical devices display damage location. The operator is then alarmed via the screen. The graphics display was configured to provide the actual intrusion location, overlaid onto the pipe line system map.

The system can recognize, locate, and alarm the operator of an intrusion within about 30 sec. The operator can quickly identify intrusion location, and dispatch personnel to the scene.

Concrete coating. As a further means of protection, the entire line was coated with a one to two-in. concrete coating, overlaid on the external corrosion coating (Fig. 1).

This concrete coating provides mechanical protection from excavation equipment, or from gouges and punctures resulting from other external force.

To get to the concrete coating, however, an excavator would have to disregard the one-call system, the above-grade line markers, sever the marker tape, and break the fiber optic trip wire.

Wall thickness. As a final means of protection, pipe wall thickness was increased to 0.432 in. (Fig. 1). The additional thickness provided mechanical protection against puncture, and allows the pipe to be gouged with much less chance of leakage.

For this relatively short, small-diameter line, additional wall thickness was an effective third-party damage mitigator.

External corrosion. DOT data indicates that roughly one-third of all reported pipe line spills and incidents are caused by external corrosion.

Generally, external corrosion of

buried pipe is an electrochemical reaction which occurs when bare (uncoated) steel comes in contact with the earth. Moist soil surrounding the line serves as an electrolyte. When the pipe metal contacts the soil, the pipe can become an anode.

Current then flows through the electrolyte, from the anode (pipe) to the cathode (soil). The anode (pipe) loses material (corrodes) as this process occurs.

The purpose of an effective external corrosion prevention program is twofold. First, the pipe is protected from corrosion by insulating it from contact with the electrolyte. This can be done through a variety of corrosion coatings.

Second, even if the coating should fail, the pipe can still be prevented from becoming the anode. This is done by introducing some other material, or an impressed current into the electrochemical chain more anodic than the pipe.

An impressed-current or sacrificial anode cathodic protection system makes the current flow through the soil, toward the pipe, instead of away from it. Corrosion coatings and well-engineered and maintained cathodic protection systems reduce the frequency of corrosion-caused spills.

For this project, the following measures were implemented to reduce the likelihood of external corrosion-caused incidents.

Corrosion coating. To determine the best coating for this project, 10 years of leak data were obtained on all regulated California hazardous liquid lines.

Ultimately, Bredero Price Pritec 1090 Coating, 10 mils butyl and 90 mils polypropylene, was selected. After reviewing the data, this coating was deemed specially suited for this hazardous liquid line.

The coating's outer polypropylene thickness was made much thicker than the typical 40-mil thickness. This extra thickness provides additional protection from external coating pinholes and other damage which can lead to leaks (Fig. 1).

Raychem two-part epoxy primer and Thermofit heat-shrinkable wraparound sleeves, (Raychem HTLP 60, 21-in. min. width) were specified to provide external protection of the field joints. This system provides two levels of pipe protection: the two-part epoxy primer and the sleeve.

The design team was concerned that the additional Pritec polypropylene thickness could cause corrosion if the Raychem shrink sleeves bridged at the coating ends.

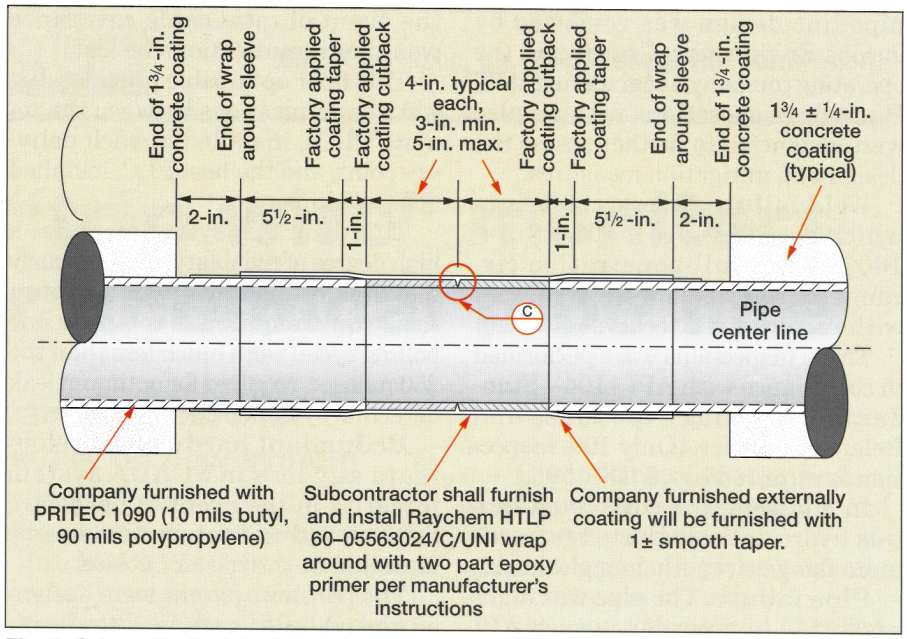


Fig. 2. Schematic depicts steps taken to prevent bridging-related corrosion at coating ends. The coating was ground at the factory to provide a smooth transition. Two-part epoxy primer was then applied to the entire field joint, up to the coating ends.

To prevent this from occurring, the coating was ground at the factory to provide a smooth transition. After the pipe at the field joint was cleaned, the two-part epoxy primer was applied to the entire field joint, up to the coating ends. The shrink wrap was then applied (Fig. 2).

Survey. After the pipe line was constructed and allowed to stabilize, two close-interval cathodic protection surveys were performed. These surveys involved taking pipe-to-soil potential readings approximately every three ft along the entire line.

One survey was performed before the cathodic protection system was commissioned. The second survey was performed after the cathodic protection system was connected to the line.

These surveys identified locations with cathodic protection levels below acceptable standards. They also identified stray currents, which can affect cathodic protection system performance.

Anodes were then commissioned to provide optimum cathodic protection levels. Periodic close interval surveys are planned to ensure that the system is maintained.

Anode. There are several pipe lines and other utilities along the right-of-way. As a result, a sacrificial anode cathodic protection system was selected to protect the chemical line.

The locations and number of anodes were optimized to provide protection well above generally accepted minimum levels, without damaging the external corrosion coating.

Other causes. Historically, roughly one-third of domestic natural gas and hazardous pipe line spills have been caused by other causes, including internal corrosion, design flaws, operator error, equipment malfunction, or pipe/weld defect.

Internal corrosion. Many chemicals, when combined with water, can be extremely corrosive. As a result, significant efforts were made to ensure that water was not introduced into the line.

After the pipe line was hydrostatically tested, all free water was removed. This was accomplished by "blowing" a series of foam pigs through the line with air.

The line was then dried by injecting nitrogen until the dew point reached at least –40°F. During this process, the line was "blocked-in" with at least 10 psig of nitrogen pressure.

Before the line was placed in service, the dew point was measured periodically, to ensure that it was maintained at –40°F or lower.

To monitor the presence of water during operation, moisture analyzers were installed on the line. These instruments were connected to the SCADA system via the PLCs. The operator interface is programmed to alarm, should moisture within the line exceed the set points.

Design flaw. Although fairly rare, design errors can cause incidents. To prevent such incidents, EDM Services'

pipe line design was reviewed by Jacobs Engineering Group, and the operating company's engineering staff. Hazardous operations reviews also were conducted to further assess the design and mitigation measures.

Weld failure. To prevent defects which could lead to weld failure, 100% of the full-penetration circumferential welds were inspected with radiographic technology.

These inspections were performed in compliance with API 1104—Standard for Welding Pipe Lines and Related Facilities. (Only 10% inspection is required by 49 CFR 195.)

In addition, the completed line was hydrostatically tested to maximum flange strength for eight hours.

Pipe failure. The pipe was manufactured in accordance with API 5L—API Specification for Line Pipe. This specification requires extensive line pipe inspections at the mill, including hydrostatic testing.

Jacobs Engineering Group also provided third-party inspection during pipe manufacture to ensure that project and API 5L requirements were met.

Spill size reduction. In general, pipe line spills can be minimized by reducing the frequency of occurrence, minimizing spill volumes, and improving emergency response.

The latter two goals can be achieved by reducing time required for locating and detecting leaks. To this end, a number of measures were implemented.

Communications. SCADA communications systems are usually provided with some combination of phone lines, microwaves, radios, and dedicated circuits.

For this project, a dedicated fiber optic communications system was selected. The system entailed a fiber optic communications cable installed alongside the pipe line, along the bottom of the ditch (Fig. 1).

As a result, in order for the communications cable to be damaged, one would have to excavate through the marker tape, trip wire, and the concrete-coated pipe.

However, even if the fiber optic communications cable is damaged, wrap back technology provides uninterrupted communications. Only in the event of total cable severance would communications be lost.

This fiber optic cable provides digital communications between the remote PLCs, installed at each delivery point, and the host PLC, installed at the shipper.

This dedicated system provides a high degree of reliability and extremely fast data communications. The scan rates (time required to complete one polling cycle) were much less than the 250 millisec. required for optimum leak detection system performance.

Redundant hardware. To eliminate any loss in SCADA system integrity in the event of hardware failure, redundant systems were installed at the host PLC site.

The parallel systems were designed and installed such that any hardware failure would provide a bumpless rollover to the backup hardware. The redundant hardware was extended to the trip wire system, the dedicated leak detection computers, the host PLC, and the host HMI.

Leak detection. *LEAKNET*, a pressure point analysis system developed by EFA Technologies, Inc., Sacramento, California, was selected for leak detection. This system incorporates two independent leak detection methods: pressure point analysis (PPA) and mass balance.

The PPA feature "looks" for pressure fluctuations that have a leak "signature." This is useful for detecting relatively small leaks in a short period.

The *MASSPACK* feature uses the traditional mass balance leak detection method. It compares volume shipped, line inventory, and delivery amount.

The EFA system uses a standard, industry-grade pressure transmitter at each pipe line end. A flow input from each end also is used for intelligent alarm processing, and the *MASSPACK* feature.

LEAKNET monitors the pressure and flow transmitters for minute pressure and flow disturbances caused by fluid exiting the pipe.

The patented, proprietary software incorporates pattern-recognition algorithms that separate normal operational events from those with a leak signature. It also is capable of detecting leaks in a static (shut-in) condition of about 4.5 ppm.

In the event of a leak, an alarm is triggered on the operator's computer monitor. The alarm display provides leak probability as calculated by the EFA software.

The leak location is then overlaid onto a pipe line system map. The system calculates and provides leak location in less than three minutes.

Redundant leak detection computers were also added. They provide continuous performance in the event of hardware failure. The EFA system was integrated into the SCADA system at the host PLC.

The system has been shown to improve an operator's ability to effect immediate emergency response. It has been installed on numerous pipe lines, including the Trans Java gas line, the Taiwan North-South gas line, and the 1,500-mi Seadrift ethylene system.

Conclusions. There are a number of technologies and programs available for reducing the likelihood and severity of hazardous material pipe line spills.

For this project, design engineers implemented the appropriate measures to minimize risk for this particular chemical pipe line. Many of these mitigation measures were (and are) site and pipe line specific.

Many other measures were evaluated during the design phase. Those presented herein were deemed most cost-effective for this project. For different terrain, pipe line contents, and pipe size, many other measures may be appropriate.

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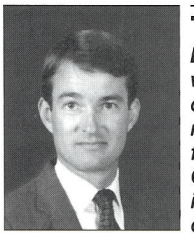

The author

***Brian Payne** is a principal with EDM Services, Inc., a consulting pipe line engineering and automation firm located in Simi Valley, California. He has been involved in the design, construction, operation, evaluation, and risk assessment of oil, gas, chemical, and utility pipe lines for 20 years. Payne holds a BS degree in civil engineering from California State University, Fresno.*

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EDM Services, Inc.

40 W. Cochran, Suite 112, Simi Valley, CA 93065 • Phone: 805-527-3300