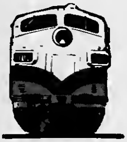
NATIONAL TRANSPORTATION SAFETY BOARD



WASHINGTON, D.C. 20594

PIPELINE ACCIDENT REPORT

MID-AMERICA PIPELINE SYSTEM
LIQUEFIED PETROLEUM GAS PIPELINE
RUPTURE AND FIRE
DONNELLSON, IOWA
AUGUST 4, 1978

UNITED STATES GOVERNMENT

TECHNICAL REPORT DOCUMENTATION PAGE

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16. Abstract

At 12:02 a.m., c.d.t., on August 4, 1978, propane that had vaporized and spread widely from a ruptured 8-inch liquefied petroleum gas (LPG) pipeline owned by the Mid-America Pipeline System (MAPCO) was ignited by an unknown source in a rural area near Donnellson, Iowa. The intense fire killed two persons and critically burned three others as they fled their homes; one of the critically burned persons later died. A farmhouse and six outbuildings were destroyed, and two adjacent homes were damaged. Before the fire burned out at 3:30 a.m., 3,750 barrels (157,500 gallons) burned and 75 acres of cornfields and woods were damaged.

The National Transportation Safety Board determines that the probable cause of the accident was the failure of an 8-inch propane pipeline due to the combined stresses that were exerted on the pipeline when it was lowered 3 months before the accident and to a dent and gouge which had weakened the pipe. The dent and gouge had been incurred before the pipeline had been completed in 1962.

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Liquefied petroleum gas (LPG); propane fire; external mechanical damage; dent; gouge; emergency valves; education; liaison; LPG statistics; pipeline lowering; construction inspection.

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Adopted: May 3, 1979

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LIQUEFIED PETROLEUM GAS PIPELINE RUPTURE AND FIRE
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SYNOPSIS

At 12:02 a.m., c.d.t., on August 4, 1978, propane that had vaporized and spread widely from a ruptured 8-inch liquefied petroleum gas (LPG) pipeline owned by the Mid-America Pipeline System (MAPCO) was ignited by an unknown source in a rural area near Donnellson, Iowa. The intense fire killed two persons and critically burned three others as they fled their homes; one of the critically burned persons later died. A farmhouse and six outbuildings were destroyed, and two adjacent homes were damaged. Before the fire burned out at 3:30 a.m., 3,750 barrels (157,500 gallons) of propane had burned and 75 acres of cornfields and woods were damaged.

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INVESTIGATION

The Accident

Several minutes before midnight on August 3, 1978, an 8-inch LPG pipeline under approximately 1,200-psig pressure ruptured in a cornfield near Donnellson, Iowa. Propane leaked from a 33-inch-long split and vaporized; the heavier-than-air gas rapidly moved through the field and across a highway, following the contour of the land. The propane gas eventually covered 75 acres of woods and fields and surrounded a farmhouse and its facilities. At 12:02 a.m., the propane vapors were ignited by an unknown source.

At 12:05 a.m., a resident notified the West Point, Iowa Volunteer Fire Department that there was a "bonfire" south of the town. When the fire department arrived at the scene between 12:15 and 12:20 a.m., firefighters found the farmhouse had already been leveled by the intense fire and there was a towering column of fire about 400 feet high located in a cornfield north of the farmhouse. Between 12:20 and 12:25 a.m., the Donnellson, Iowa Volunteer Fire Department arrived at the scene and both departments began extinguishing numerous brush fires. (See figure 1.)

Both fire departments stated that they did not know the locations of any shutoff valves, nor did they know who in the area could help them locate the valves. They stated that they had not received instruction or information concerning the hazards of LPG or how to handle an incident of this magnitude from the pipeline company or the State Fire Marshal. They said all they could do was to control the brush fires and hope someone was closing valves that would stop the escaping propane.

At 12:06 a.m., the MAPCO dispatching control center at Tulsa, Oklahoma, recorded an audible alarm indicating that the pressure at the terminal on the 8-inch Farmington, Illinois lateral of the pipeline had dropped below a pressure limit set point of 800 psig. Although the Farmington lateral was not operating, it was under a static pressure of over 1,200 psig. A previous computer printout of pressures at various points throughout the system had shown that the pressure at the Farmington terminal was 1,266 psig at 23:59:33 hours.

The dispatcher had requested the Iowa City terminal to open a suction pressure control valve there on the main line (see figure 2) sometime between 11 p.m. and midnight. The dispatcher said he thought that the valve might have been opened more than necessary; this would have caused such a pressure drop. Therefore, he did not immediately suspect a leak in the system.

At 12:15 a.m., the dispatcher observed that the suction pressure at Iowa City had dropped 200 psig and that the discharge pressure at the pump station at Birmingham Junction, Iowa had also dropped. The dispatcher then teletyped the Iowa City terminal requesting it to increase the back pressure by 200 psig to bring the suction pressure at the terminal back up to 500 psig where it had been previously. The automatic valve that controls the back pressure into the terminal was not operating, so this was done manually by the terminal operator.

At 12:20 a.m., after monitoring the continued drop in pressures, the dispatcher decided that there might be a leak in the system. Since he was not certain whether the pressure loss was on the main line between Birmingham Junction and Iowa City or whether it was on the Farmington lateral, the dispatcher at 12:23:44 hours remotely closed the valve at the Birmingham Junction pump station that isolated the 117 miles of pipeline on the Farmington lateral. The pressure immediately started to increase on the discharge side of the Birmingham Junction pump station on the line between Birmingham Junction and Iowa City; this

Figure 1. View of the burned area.

Figure 2. Plan view of pipeline route.

increase indicated that the pressure loss was on the Farmington lateral. The dispatcher then called his supervisor to inform him that there appeared to be a leak on the Farmington lateral. He was instructed to notify another supervisor to send the area maintenance crew to start looking for the leak.

At 12:33 a.m., while the dispatcher was talking by telephone with the second supervisor, a resident of Donnellson, Iowa, called to give the first confirmed report of a pipeline rupture at milepost 33 just east of his farm adjacent to Highway 2 in Lee County. The dispatcher gave the location of the rupture to the supervisor and proceeded to shut down the rest of the system in case the remote valve at the Birmingham Junction station did not close tightly.

At 12:40 a.m., the dispatcher notified the MAPCO employee living closest to the rupture site and asked him to close the block valve just west of the rupture at milepost 32. At 12:41 a.m., the dispatcher called the Lee County Sheriff's office whose personnel were already at the scene. He advised that office to instruct the fire department not to attempt to extinguish the fire at the rupture.

At 12:43 a.m., the dispatcher telephoned the local resident who had reported the rupture and asked him to close the block valve at milepost 32. The resident said he would try, even if he had to cut the chain that prevented the unauthorized operation of the valve. The dispatcher continued to shut down the system and at 12:55 a.m., after checking the charts to see the location of the next block valve east of the rupture, he notified another employee to close the valve at milepost 36.8.

During this time, MAPCO personnel were unaware that another area resident, who had heard the sound of the gas ignition at his house and had gone to the accident site, had already gone to the locations of both block valves on either side of the rupture, cut the chains, and closed the valves. He closed the valve at milepost 32 at 12:30 a.m. and closed the valve at milepost 36.8 at 1:00 a.m. He had not been authorized to do this by MAPCO, but he said be acted because he knew about the location of the pipeline and the valves, and because he correctly assumed that it was the MAPCO line that had failed. At 1:35 a.m. and 2:15 a.m., MAPCO personnel notified the dispatcher that the block valves which they were instructed to close had already been closed when they arrived. The fire at the rupture continued while the LPG remaining in the pipeline between the closed valves burned until 3:30 a.m.

Injuries to Persons

Injuries	Operating Personnel	Rescue Personnel	Other
Fatal	0	0	3
Nonfatal	0	0	2

Damage to Pipeline

A segment of 8-inch pipe approximately 64 feet long containing the 3-foot ruptured section was removed from the system. (See figure 3.) Approximately 3,750 barrels (157,500 gallons) of liquid propane had vaporized and burned.

Other Damage

One farmhouse, six outbuildings, and an automobile were destroyed (see figure 4), and two houses and an automobile were damaged by the fire. Electric power lines and telephone lines were burned down and approximately 75 acres of woods and cornfields were burned.

The Pipeline System

MAPCO, a common carrier LPG pipeline, extends from west Texas to Conway, Kansas, where it forms two branches. One branch extends to Minneapolis, Minnesota and the other extends to Janesville, Wisconsin. The pipeline system contains more than 5,000 miles of multiple lines from 4 inches to 12 inches in diameter which cross the States of New Mexico, Texas, Oklahoma, Kansas, Nebraska, Missouri, Iowa, Illinois, Minnesota, and Wisconsin. MAPCO transports eight liquefiable hydrocarbons. Ethane-propane mix, propane, iso-butane, normal butane, butane mix, natural gasoline, and a demethanized mix. The original system constructed in 1960 consisted of 2,200 miles of pipelines. Additional lines were added in 1961, 1967, 1968, 1969, and later. (See figure 5.)

The section of pipeline involved in this accident extends from a pump station at Birmingham Junction, Iowa, to storage tanks at a terminal in Farmington, Illinois, a distance of 117 miles. This section of pipeline is called the Farmington lateral and was engineered and inspected by MAPCO personnel and installed by an independent contractor in 1962. The line was constructed in accordance with the American Standard Code for Pressure Piping. This was the industrywide code and suggested practice for liquid petroleum pipelines at that time.

The 8 5/8-inch O.D., 0.156-inch wall, API 5LX, Grade 52 line pipe was manufactured by the electric-resistance welding process. The pipe was coated and wrapped, cathodically protected by rectifiers, and had 4 feet of cover at the point of rupture. The pipe was inspected at the steel mill, again when it was unloaded and stockpiled, again when it was coated, and finally when the coating was being inspected before the pipe was lowered into the ditch.

The pipeline was hydrostatically tested to 1,350 psig for 24 hours before it was put into operation in 1962. At that time this was MAPCO's practice for determining maximum allowable operating pressure (MAOP). Therefore, the 1,350-psig pressure was established as the MAOP for this line.

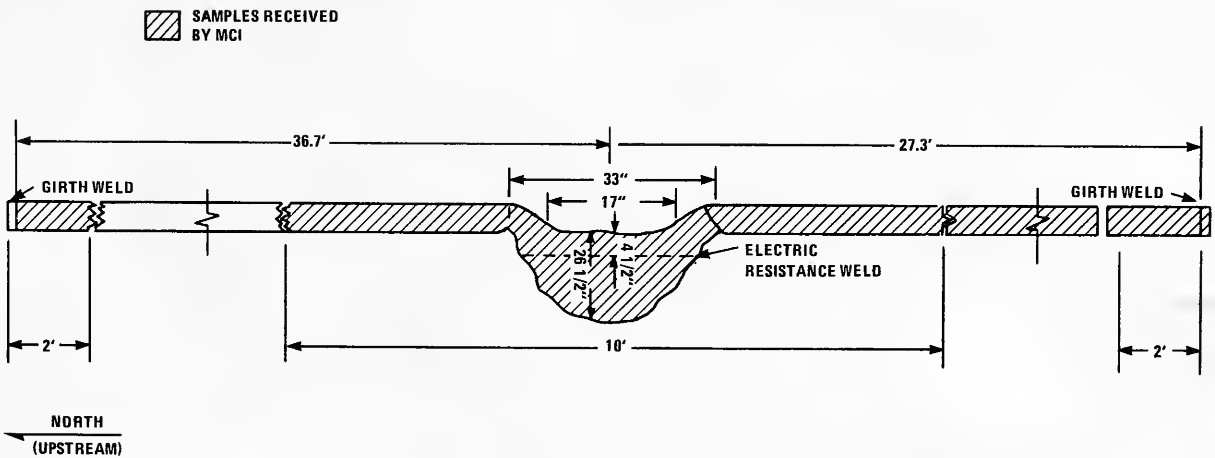

Figure 3. An 8-inch segment of pipe containing the 3-foot ruptured section.

Figure 4. An aerial view of the farmhouses and other outbuildings destroyed.

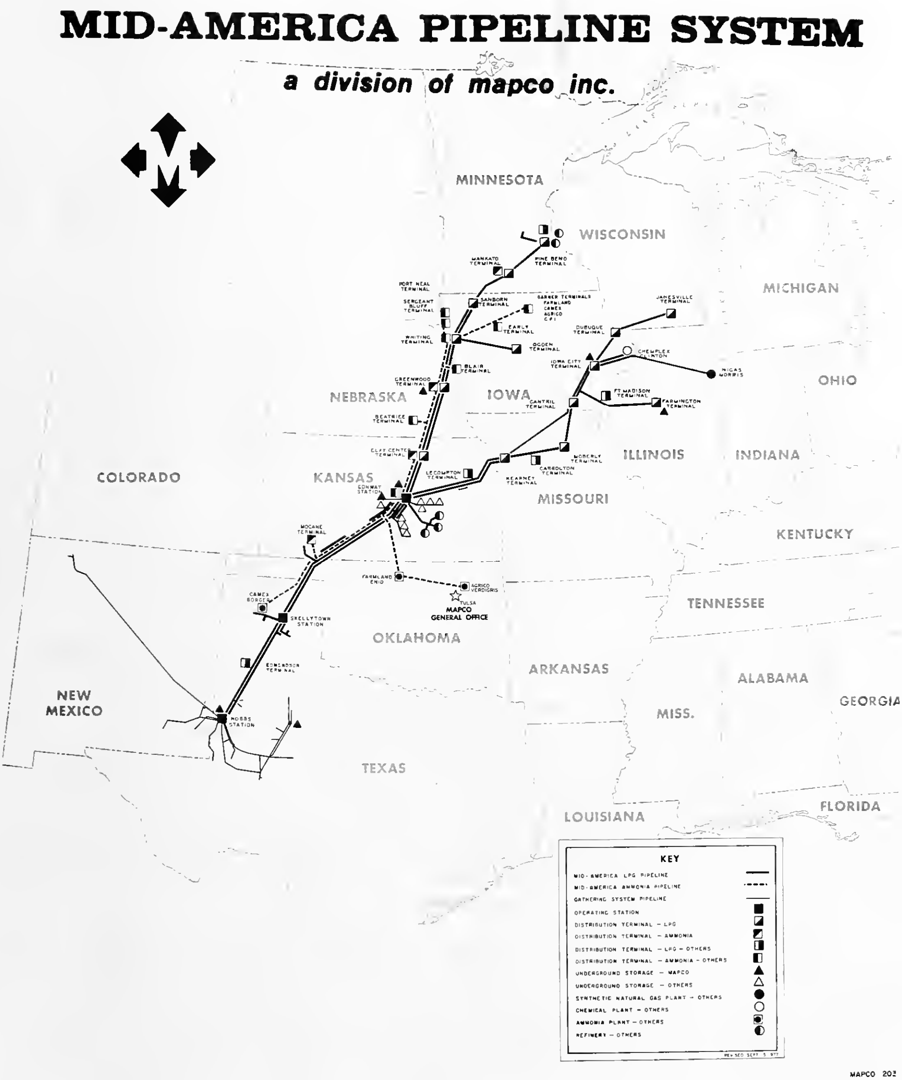

Figure 5. MAPCO pipeline system.

The American Standard Code for Pressure Piping, Oil Transportation Piping, ASA B31.4-1959, Section 437.4.1(a), Hydrostatic Testing, states:

> Portions of oil transportation piping systems to be operated at hoop stress exceeding 30 percent of the specified minimum yield strength of the pipe shall be subjected to a hydrostatic test (water or oil) equivalent to not less than 1.1 times the internal design pressure (see paragraph 401.2.2). However, in no case shall it be required that the test pressure at any point of the line be such as to produce a hoop stress based on nominal wall thickness in excess of 90 percent of the specified minimum yield strength.

Section 401.2.2, Internal Design Pressure of the code states:

> Internal Design Pressure (maximum internal liquid pressure) shall not be less than the Maximum Working Pressure plus allowance for surge pressure if anticipated. Suitable protective devices of such types as relief valves and automatic shutdown equipment shall be provided which will assure that the maximum internal design liquid pressure of the piping system and equipment is not exceeded by more than 10 percent.

Under the existing Federal regulations (49 CFR 195) for liquid petroleum pipelines, which were not in effect at the time this pipeline was constructed, the MAOP for this pipeline would be 80 percent of the test pressure or 1,080 psig.

When the station at Birmingham Junction is pumping to the Farmington terminal, a pressure controller regulates the pressure to 1,350 psig. If for any reason this pressure is exceeded, a motor-operated valve closes automatically when the discharge pressure at Birmingham Junction reaches 1,400 psig. This valve can also be remotely operated by the dispatcher at Tulsa. At the Farmington terminal a control valve regulates the back pressure at the terminal to 200 psig. In essence, when the line is in operation from Birmingham Junction to the Farmington terminal, the discharge pressure at Birmingham Junction is controlled at 1,350 psig maximum and the pressure decreases along the 117-mile pipeline to 200 psig at the Farmington terminal back-pressure valve.

From 1962 until 1975 the line from Birmingham Junction to the Farmington terminal was closed in under pressure (approximately 200 to 300 psig) when the line was not in operation. The procedure was changed however in 1975 when the line was left open at Birmingham Junction whether or not LPG was being pumped into the Farmington terminal. This open line condition created a relatively flat hydraulic curve over the entire 117-mile pipeline with the result that, except for elevation differences along the pipeline, the pressure was the same at Birmingham Junction and at the Farmington terminal--a possible maximum of 1,350 psig. This was the condition at the time of the accident.

The Farmington terminal at the end of the 117-mile pipeline sector has underground, mined LPG storage caverns; aboveground, steel, LPG-pressure vessel storage tanks; and truck loading facilities. The LPG is delivered into the terminal storage under 150- to 200-psig pressure. When the LPG is transferred from storage to the truck loading facilities, it is odorized with a mercaptan compound for the ready detection of an otherwise almost odorless material. The LPG leaves the terminal in tank trucks for delivery to industrial, commercial, and residential customers for use as a fuel for heating and cooking. Additional amounts of LPG are used for peak shaving 1/ in gas distribution systems.

There are 10 block valves on this 117-mile lateral that are spaced as close as 2.2 miles at a river crossing to as far as 22 miles apart across farmland. Since MAPCO's maintenance personnel are deployed over several States, MAPCO incorporates into its emergency plans a list of persons, usually residents along the pipeline right-of-way, to contact in an emergency. These persons are given keys that allow them to close certain valves. This list of valves and persons to contact in an emergency was obsolete and was not used by the dispatcher during this accident. Two of the persons listed were deceased; one had died in 1973. Other persons had moved or their telephone numbers had changed. The list also did not include a critical valve located on the west side of the Mississippi River at milepost 36.8. The district fire departments near the accident site did not have a list of persons that they could contact to close valves in an emergency and did not know the location of all the valves.

The entire MAPCO system is controlled primarily from the dispatching headquarters at Tulsa, Oklahoma, with secondary control centers at Hobbs, New Mexico; Conway, Kansas; and Iowa City, Iowa. Pressure recordings from all terminals and pump stations are telemetered back to these control centers. In addition, the control centers monitor the amount of LPG metered into and out of the system so that any anomalies--from small leaks to line ruptures--can be detected by either pressure loss or input-output variance. This computerized information, both the metered LPG and the pressure, can be monitored on a cathode ray tube (CRT) display in the Tulsa center. The computer scans the entire pipeline system continuously every 15 seconds and sounds an audible alarm and displays on the CRT any abnormal variations of pressure or flow within the pipeline system. This information can also be printed out at the dispatcher's command. Every hour the amount of LPG entering the system is recorded and checked against the amount of LPG leaving the system.

There are two dispatchers at Tulsa on duty on each 8-hour shift; the center is manned continuously. One dispatcher at Tulsa controls the system from Hobbs to Conway. The other dispatcher at Tulsa controls the

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1/ Peak shaving is the practice of injecting propane in gaseous form into gas distribution systems to supplement natural gas supplies during periods of high consumption.

two legs of the pipeline from Conway north. (See figure 5.) During the day, a supervisor and four other persons are also on duty at the control center.

Meteorological Information

The night of the accident was clear with visibility of 12 to 15 miles. There was a light north-northwesterly wind of 4 to 8 knots and the temperatures were in the upper 50's. The wind was nearly constant from the surface to about 4,000 feet m.s.l.

Fire

The farmhouse and outbuildings destroyed by the fire were completely engulfed when the fire departments arrived at the scene. Smaller fires in the woods and adjacent homes were extinguished, but the huge fire at the ruptured pipe was left burning until valves had been shut off to isolate the failed section. The remainder of the LPG then burned out. A 75-acre area of farmland and woods were burned.

The four volunteer fire departments that responded to the fire had not received instructions or educational material on the hazards of LPG from MAPCO or the Iowa State Fire Marshal, nor had they previously encountered an LPG fire of this magnitude.

Survival Aspects

Two persons died inside the farmhouse that was engulfed in flames when the propane was ignited. Three persons who lived across the highway from the ruptured line had heard the pipeline burst and were fleeing their house when the propane ignited. All three persons received burns on over 90 percent of their bodies; one person later died from the burns.

When liquid propane escapes from a ruptured pipeline, it vaporizes and expands rapidly, absorbing a tremendous amount of heat for this expansion from any substance with which it comes in contact. When the propane gas ignites, it is slow burning with an extremely hot flame. Therefore, if the burns are extensive, the chance of survival is generally low.

Tests and Research

On August 4, 1978, a 64-foot section of pipe was removed at the rupture site. Three samples were cut from the section for metallurgical analysis and examination: a 10-foot section which contained the failure, and two 2-foot pieces from each end of the failed length of pipe. (See figure 6.) The Safety Board retained Metallurgical Consultants, Inc., of Houston, Texas, to conduct testing and metallurgical analysis of the failed pipe.

Figure 6. Drawing showing details of ruptured pipe and location of samples.

The metallurgical examination concluded that the failure of the pipe was caused by external mechanical damage in the form of a dent and a gouge. The damage was located at the 4 o'clock position in the pipe. The damaged section was relatively small and would have been difficult to detect with the naked eye. Because of fire damage to the pipe, it was impossible to determine whether the dent and gouge occurred before or after coating operations. (See appendix A.)

A metallurgist from the Safety Board's Laboratory Services Division reviewed the metallurgical report and determined that there was no evidence of a fatigue failure or a progressive failure mechanism. The fracture features of the failed piece were typical of an overload failure mechanism, however. (See appendix B.)

Three months before the accident, MAPCO completed lowering a section of the Farmington lateral under Highway 2 adjacent to the accident site. (See figure 7.) After the accident, it was determined that MAPCO had started lowering the pipeline 15 feet from where the rupture occurred and the pipe elevation had changed 10 feet along 170 feet of pipe north from that point.

The Safety Board requested the Federal Highway Administration (FHWA) of the U.S. Department of Transportation, to determine what stresses might have been exerted on the pipeline by it being lowered. The FHWA report (see appendix C) concluded that:

1. Stress exerted on the pipeline due to lowering of the pipe was 11,444 psi.

2. Stress exerted on the pipeline due to internal pressure was 16,884 psi.

3. Stress exerted on the pipeline due to weight of pipe was 1,752 psi.

4. Stress exerted on the pipeline due to weight of product (liquid propane) in the pipe was 1,251 psi.

5. Stress exerted on the pipeline due to earth load with no arching effect was 43,400 psi.

The report further concluded that these combined stresses, when applied at the location of the dent and gouge, caused a stress concentration that increased the total stress by 2 to 3 times. This total stress far exceeded the tensile strength of the pipe steel and caused the pipeline to rupture at the weakened point. The calculations represent an order of magnitude of forces imposed upon the pipeline at the time of the accident.

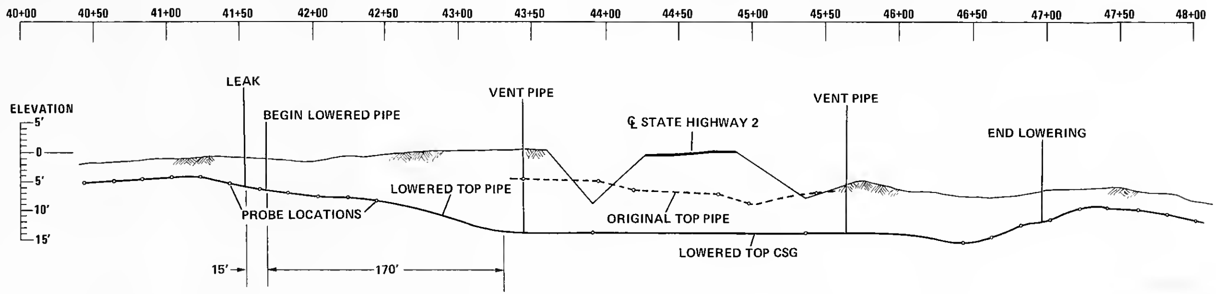


Figure 7. Drawing showing elevation of pipeline.

Other Information

Events preceding the accident. -- MAPCO lowered the pipeline 3 months before the accident in conjunction with road work on Highway 2 adjacent to the accident site. Because of the widening of the highway and the depth of the drainage ditches on each side of the road, it was necessary to lower the pipeline more than 11 feet. (See figure 7.) In order to obtain enough slack in the pipeline to lower it this much, the company's "rule of thumb" practice required that for every foot the 8-inch steel pipe was to be lowered, a 35-foot-long section had to be exposed. MAPCO and contractor personnel excavated a trench 237 feet from the north side of the highway along the pipeline. The crew supervisor stated that they left a column of dirt under the pipeline for support approximately every 30 feet. The pipeline was exposed to within 15 feet from where the rupture subsequently occurred. The crew then cut south across the highway and dug a trench exposing the pipeline for another 290 feet. After the pipeline was reportedly lowered slowly and allowed to follow the contour of the trench, the trench was backfilled and compacted. Additional casing was added to the original casing on the section of pipeline across the highway before backfill. The pipeline was not operating at the time the line was lowered; however, it did have a static pressure of 200 to 250 psig. Heavy rains causing muddy conditions hampered the line-lowering project.

An area resident stated that based upon his observations of the lowering of the pipeline, "There were no pillars of ground underneath the pipeline when they were lowering it. It was too muddy. That ground was just saturated....They had a sling wrapped around the pipeline and they were holding it up with a bucket on the backhoe." 2/

Before this lowering project, MAPCO had not excavated in this location since the initial pipeline construction. Long-time area residents stated that they were not aware of any excavation work near the pipeline in this area. State and local authorities did not have records of previous excavation work near the pipeline in this area.

Pipeline failures on the Farmington lateral. -- Before the accident, the Farmington lateral had had two other failures since it was put into operation in 1962. Both failures were caused by third-party damage. On September 3, 1968, in Fulton County, Illinois, a coal company digger ruptured the pipeline. This incident caused the death of one person and four injuries. On May 23, 1977, in Peoria County, Illinois, a tiling machine punctured the pipeline. There were no deaths or injuries in that incident.

2/ Transcript of Proceedings, NTSB Public Hearing held in Des Moines, Iowa, September 26, 1978, pp. 68 and 69.

After the Donnellson pipeline rupture was repaired, a hydrostatic test was made on the entire 117-mile Farmington lateral. The pipeline experienced 17 failures during the hydrostatic retest. The failures occurred at test pressures from as low as 1,465 pounds to a high of 1,810 pounds. Excavation of the pipe at these failures showed that 15 were seam failures and 2 were caused by mechanical damage previously done. Representatives of Metallurgical Consultants, Inc., visually inspected the two failures with mechanical damage; the company stated that both failures "...appeared to be rather severe mechanical damage." It could not be determined when the pipeline had been damaged at these two locations.

LPG pipeline accidents.--The Safety Board has investigated five other major pipeline accidents involving LPG. 3/ After investigating the LPG accident in Franklin County, Missouri, the Board recommended on March 1, 1972, that the Federal Railroad Administration, the agency responsible at that time for the regulation of liquid petroleum pipelines:

1. Undertake rulemakings to provide for more complete controls for the pipeline transportation of LPG;

2. Study minimum valve spacing standards and the use of more automatic or remotely operated valves on LPG pipelines;

3. Study the methods of handling, containing, and disposing of LPG spilled from pipeline failures and amend applicable regulations.

3/ "Pipeline Accident Report--Phillips Pipe Line Company Propane Gas Explosion, Franklin County, Missouri, December 9, 1970" (NTSB-PAR-72-1).

"Pipeline Accident Report--Phillips Pipe Line Company Natural Gas Liquid Fire, Austin, Texas, February 22, 1973" (NTSB-PAR-73-4).

"Pipeline Accident Report--Dow Chemical U.S.A. Natural Gas Liquid Explosion and Fire, Devers, Texas, May 12, 1975" (NTSB-PAR-76-5).

"Pipeline Accident Report--Sun Pipe Line Company Rupture of 8-Inch Pipeline, Romulus, Michigan, August 2, 1975" (NTSB-PAR-76-7).

"Pipeline Accident Report--Consolidated Gas Supply Corporation Propane Pipeline Rupture and Fire, Ruff Creek, Pennsylvania, July 20, 1977" (NTSB-PAR-78-1).

After investigating the accident in Austin, Texas, the Board recommended on November 7, 1973, that the Office of Pipeline Safety (OPS), which was now responsible for LPG regulations, to expedite the rulemaking for LPG and to establish an educational program to enable the public to recognize, detect, and alert the proper personnel of leaking LPG.

The Safety Board's 1976 report of its investigation of the accident in Devers, Texas on March 12, 1975 emphasized that LPG's "...unique behavior warrants more stringent controls than those for other liquid petroleum products."

After investigating the accident in Ruff Creek, Pennsylvania, the Safety Board again recommended on January 12, 1978, that the OPSO 4/ "expedite the publishing of the Notice of Proposed Rulemaking on regulations for the safe transportation by pipelines of liquefied petroleum gases (LPG)."

Pipeline Safety Regulations.--In early practice, liquid pipelines were designed, constructed, and pressure-tested according to individual company practices, and then placed in service. Policies relating to the safe operation and maintenance of these pipelines were guided by both industry and individual State requirements. Later, legislation was enacted that allowed the Interstate Commerce Commission (ICC) to be responsible for safety regulations for the interstate liquid petroleum pipeline industry. In 1967, these responsibilities were transferred to the U.S. Department of Transportation (DOT) for administration by the Federal Railroad Administration (FRA). The FRA had the authority over liquid petroleum pipeline carriers; however, the FRA received technical advice from the DOT's Office of Pipeline Safety. In 1972, the authority for the regulation of liquid petroleum pipelines was turned over to the Director of the Office of Pipeline Safety.

On February 27, 1978, in a statement prepared for a Senate Committee on Commerce, Science and Transportation, the U.S. General Accounting Office said: "The regulations issued by the Pipeline Safety Office do not cover all pipeline facilities and in some cases are not effective for ensuring the public safety...." 5/ The statement also mentioned that "Priority attention also needs to be given to the transportation of highly volatile liquids, such as liquefied petroleum gas and anhydrous ammonia. Although these liquids are much more hazardous than other liquids, Federal Safety Regulations do not distinguish among the various liquid commodities by requiring higher levels of safety for the more hazardous ones...." It continued to say that "Despite the disproportionate casualties and damage attributed to these liquids, and despite repeated recommendations by the National Transportation Safety Board, more stringent pipeline safety standards have not been issued...."

4/ The Office of Pipeline Safety became the Office of Pipeline Safety Operations (OPSO) in 1975. OPSO is part of the DOT's Materials Transportation Bureau.

5/ "The Effectiveness of the Federal Pipeline Safety Program," U.S. General Accounting Office, Director, Community and Economic Division, February 27, 1978.

On August 8, 1978, the OPSO issued its first of three Notices of Proposed Rulemaking (NPRM) about LPG pipelines. The first concerned maintenance, operating, and emergency procedures; the second, issued August 28, 1978, concerned valve types and valve spacing; and the third, issued November 7, 1978, concerned testing LPG pipelines. The OPSO has not yet issued any regulations as a result of the Safety Board's recommendations or of the rulemaking process.

ANALYSIS

The metallurgical analysis concluded that the pipe failed at an area that had been dented and gouged previously. The stress analysis concluded that the lowering of the pipeline created conditions that produced stresses in the pipe. These stresses, when combined with the stress caused by the operating internal pressure (hoop stress) of the pipeline at the time of the accident, were calculated to be higher than the yield strength of the steel. Further analysis showed that with a stress concentrator--dent and gouge--these stresses increased by a factor of three. If the pipeline had not been dented and gouged, the line-lowering project probably would not have caused the pipeline to fail.

When the 117-mile lateral was hydrostatically retested after this accident, two other dented and gouged areas failed at pressures considerably higher than that at the time of the accident failure. In both cases, the dents and gouges were much more pronounced than that at the accident site, but while these two larger dents and gouges had been subjected to the same operating pressures as had the much smaller dent and gouge at the accident site, they had not failed. The pipeline at the accident site had been subjected to critical stresses caused by the line lowering; the pipeline at the location of the larger dents and gouges had not been disturbed. The line lowering was the final factor contributing to this accident.

Therefore, the Safety Board concludes that when these combined stresses were exerted at the location of the dent and gouge, the stress concentration that resulted far exceeded the tensile strength of the pipe steel and caused the pipeline to rupture at the weakened point.

MAPCO's "rule of thumb" for lowering the pipeline required exposing 35 feet of pipe for every 1 foot it was to be lowered. Although the pipeline was lowered more than 11 feet and a total of 527 feet of pipeline was exposed, the pipeline was not lowered at a consistent rate. MAPCO started lowering the pipeline 15 feet from where the rupture occurred and the pipe elevation had changed 10 feet along 170 feet of pipe from that point. If the company had exposed the pipeline beyond where the rupture occurred, it would have been able to obtain a more gradual change in elevation and substantially reduce the stresses exerted on the pipeline. This precaution probably would have prevented the accident.

The pipe involved in this accident had a wall thickness of 0.156 inch. The industry piping code lists 0.104 inch as the least wall thickness recommended for 8 5/8-inch O.D. line. 6/ Steel mills commonly manufacture 8 5/8-inch O.D. line pipe in wall thicknesses up to 0.500 inch; some mills quote specifications up to 0.875 inch. In the range of wall thicknesses from 0.104 to 0.500 inch, 0.156 inch wall pipe lies in the first 20 percent--on the thin side--of the total range.

Pipelines handling LPG, which the Safety Board has repeatedly shown to be a hazardous product that cannot be contained, controlled, or dispersed safely after escaping from a pipeline rupture, are not required by OPSO regulations to have either heavier walled pipe, tougher pipe, stronger pipe, or better pipe than other pipelines. Metallurgists can debate whether heavier wall pipe or tougher pipe may be more rupture-free than the pipe in this accident, but until some formal effort is made in this direction, accidents like this one, caused by previous damage to the pipe, will probably continue. The Safety Board believes that pipe can be manufactured to transport LPG more safely.

MAPCO records indicated that no excavation activities by either the company or by others had been undertaken in or near the rupture area. Area residents stated that no excavation activities other than lowering the pipe had been undertaken at the rupture area. These facts indicate that the damage was done somewhere between the steel mill where the pipe was manufactured and where the pipeline was constructed. The dent and gouge were located at the 4 o'clock position in the pipe. The damaged section was relatively small and would have been difficult to detect with the naked eye; nevertheless, the small dent and gouge did weaken the pipe steel and contribute to this accident. Although the small size of the damage and its location--toward the bottom of the pipe--would have made detection difficult, the Safety Board believes that a careful, thorough inspection of the pipe during construction might have revealed the damage.

At the time of the accident, propane was being transported through MAPCO's main pipeline system to Iowa City. The Farmington lateral which branches off the main line downstream of the Birmingham Junction pump station was not operating, but was under a static pressure. The remotely operated valve at the pump station that isolates the lateral was in the open position whether product was being delivered to the Farmington terminal or the Iowa City terminal or both. Therefore, the static pressure on the lateral was almost the same as the discharge pressure of the pump station except for line elevation differences. Because the suction pressure at the Iowa City Terminal was controlled manually, the dispatcher, in the control center at Tulsa, did not anticipate that a rupture had occurred when the pressures started to decrease. His first

6/ Table 404.1.1, "Least Nominal Wall Thickness for Steel Pipe," American National Standards Code for Pressure Piping, Liquid Petroleum Transportation Piping Systems, ANSI B31.4-1974.

reaction to the pressure drop was that the suction pressure control valve had been opened more than was previously requested. Because of these conditions it took the dispatcher 25 minutes to realize that there was a problem.

If the valve that isolates the Farmington lateral had been closed at the time of the accident, the dispatcher would have known almost immediately that the pressure drop was on the lateral and was not due to operating conditions in the main line. This information would have enabled the dispatcher to initiate an emergency response shortly before midnight instead of 12:23 a.m.; in another accident this time difference might prevent a catastrophe. As a result of this accident, MAPCO has established a policy that the isolation valve for the Farmington lateral at the Birmingham Junction pump station be closed when the product is not moving through this lateral.

The list of persons to contact in an emergency to close valves on the Farmington lateral was not used by the dispatcher. Even if it had been, it would not have been effective because it was outdated. This list, however, was supposed to be kept current with the correct telephone numbers and should have included information about all valves on the lateral. In another accident in a different location, the rapid, positive valve closures could prevent a catastrophe. Therefore, if the list of names is part of the emergency procedures, the list should be kept current and should be used in an emergency.

MAPCO had not given instruction and education about procedures to follow in the event of a pipeline failure to area emergency personnel. State agencies, fire departments, and local police should be informed about pipeline locations, valve locations, emergency telephone numbers, the hazards of LPG, and how to handle LPG accidents. Liaison and cooperation between MAPCO and these emergency groups is vital in protecting the general public and residents along the pipeline right-of-way. If the local residents are aware of the behavior of LPG, and if the fire and police departments have received adequate training in the handling of leaking LPG, the risk to the public can be reduced.

Statistics show that LPG is more hazardous than other petroleum products. Since 1972, the Safety Board's investigations of LPG accidents have resulted in 11 recommendations regarding rulemaking to make regulations for LPG pipelines more stringent. The Safety Board notes that it has been 8 months since the OPSO issued it's first NPRM about LPG pipelines. The Safety Board concludes that the OPSO should reevaluate its positions on all of the recommendations made by the Safety Board to the OPSO concerning LPG and expedite those that require rulemaking.

CONCLUSIONS

Findings

1. The rupture in the 8-inch propane pipeline was due to the combined stresses that were exerted on the pipeline when it was lowered 3 months before the accident.

2. The failure occurred at an area on the pipe that had been dented and gouged previously.

3. The dent and gouge in the pipe occurred sometime between manufacture of the pipe and the construction of the pipeline.

4. The leaking propane vaporized and migrated over a 75-acre area within minutes before it was ignited by an unknown source.

5. Due to operating procedures at that time, MAPCO's personnel did not realize there was a leak in the system until 25 minutes after the rupture occurred.

6. If the valve at Birmingham Junction had been closed at the time of the accident the pressure drop would have been larger and would have rapidly shown the trouble to be on the Farmington section of the pipeline.

7. Public emergency response personnel who responded to the accident had not received any instruction or education from MAPCO on the hazards of LPG and how to handle an LPG fire.

8. MAPCO's list of persons to contact to close specific valves for the Farmington lateral in case of an emergency was not kept current nor was it used by the dispatcher.

9. The OPSO has not differentiated between highly volatile liquid petroleum pipelines and other liquid petroleum pipelines in its regulations for liquid petroleum transportation.

10. The OPSO should expedite action on Safety Board recommendations concerning LPG regulations.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was the failure of an 8-inch propane pipeline due to the combined stresses that were exerted on the pipeline when it was lowered 3 months before the accident and to a dent and gouge which had weakened the pipe. The dent and gouge had been incurred before the pipeline had been completed in 1962.

RECOMMENDATIONS

During its investigation of this accident, the National Transportation Safety Board recommended that the Mid-America Pipeline System:

"Update the list of individuals who should be contacted to close specific valves in the event of an emergency and institute a procedure to assure that the list is updated at least annually. (Class I, Urgent Action)(P-78-66)

"Conduct periodic training for public emergency response agencies along the route of its pipelines. As a minimum, this training should be conducted annually and be sufficient to inform emergency response agencies of the properties of the various products transported, the expected behavior of each product when released to the atmosphere, the locations of shutdown valves, the residents designated to operate each valve, and other information necessary for emergency response personnel to take effective actions and minimize losses. (Class I, Urgent Action)(P-78-67)"

As a result of its complete investigation of this accident, the National Transportation Safety Board made the following recommendations:

-- to the Mid-America Pipeline System:

"Determine by analytical means the stresses produced on the pipe steel when projects require the lowering of a section of pipeline, and design a safety factor to insure that these stresses will not affect the integrity of the line. (Class II, Priority Action)(P-79-2)

"Establish written procedures that require its personnel to ascertain that precautions are taken in the field to eliminate excessive or sudden changes in elevation when lowering a section of pipeline. (Class II, Priority Action) (P-79-3)

"Emphasize to its pipeline construction inspection personnel the importance of careful, thorough inspection to minimize the occurrence of dents and gouges which could result in similar accidents. (Class II, Priority Action)(P-79-4)

"Check all other segments of its pipeline for conditions similar to the open valve condition in the line section involved in this accident and make changes or additions as required. (Class II, Priority Action)(P-79-5)"

-- to the Materials Transportation Bureau of the U.S. Department of Transportation:

"Reevaluate all recommendations made by the Safety Board concerning LPG, and expedite those that require rulemaking. (Class II, Priority Action)(P-79-6)"

-- to the American Petroleum Institute:

"Advise its member companies who operate similar LPG pipelines of the importance of careful, thorough inspection during pipeline construction to minimize the incidence of dents and gouges which could result in similar accidents, and bring to their attention the need to use proper engineering techniques when it is necessary to relocate or lower a section of pipeline. (Class II, Priority Action)(P-79-7)"

-- to the American Iron and Steel Institute and the American Petroleum Institute:

"Undertake research for more stringent specifications for line pipe manufactured for LPG pipeline service to minimize or mitigate the effects of dents and gouges. Consideration should be given to the research currently being conducted by the American Gas Association on this problem. (Class II, Priority Action)(P-79-8)"

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ ELWOOD T. DRIVER
Vice Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ PHILIP A. HOGUE
Member

May 3, 1979

APPENDIX A

Excerpts of "Metallurgical Examination of Pipe from an LPG Pipeline Failure at Donnellson, Iowa, August 4, 1978," Metallurgical Consultants, Inc., Houston, Texas.

Examination of Ruptured Pipe

The rupture was approximately 33 inches long and originated on the west side of the line. It propagated longitudinally about 17 inches and then spiralled over 360 degrees at each end and stopped. The failed section created by the force of the failure as the pipe wall was blown outward below the fracture traveled under and around the pipe. (See figure 8.) Close examination of the outside surface showed gouge marks along and on either side of the fracture. The most severe gouge was approximately 7 1/2 inches long and 1/4 inch wide and located along the bottom side of the fracture. (See figure 9.) The fracture surfaces near the center of this gouge were very flat and brittle--appearing over a length of about 2 1/2 inches. The fracture changed from flat to approximately 45 degrees with the typical appearance of shear. The fracture surface also reveals an irregular fracture profile with fine cracks on each side of the fracture. The depth of the gouge was approximately 0.005 to 0.007 inch.

Wall thickness measurements were made of the unaffected pipe wall on each side of the 17-inch-long, longitudinal fracture and were within the range 0.150 to 0.156 inch. The minimum wall thickness for this pipe according to the American Petroleum Institute (API) specification for high-test line pipe is 0.137 inch.

Sections for metallographic examination were cut across the fracture and gouge at four locations within the white arrows. Matching specimens were cut from above and below the fracture, mounted together, polished, and etched. The manner in which the matching fractures fit together indicate that the pipe had been dented as well as gouged. (See figure 10.) On three of the sections, small secondary cracks were found. The largest crack as shown in section B was approximately 0.015 inch deep. It was very straight for a depth of about 0.008 inch, then veered off at an angle. The offset in the fracture at the outside surface was similar in shape to the small crack. (See figure 9.)

Chemical analysis and transverse tensile tests on the pipe steel conducted on the section of pipe adjacent to the failed area revealed that it met the chemical and yield requirements by the API established for this type of pipe.

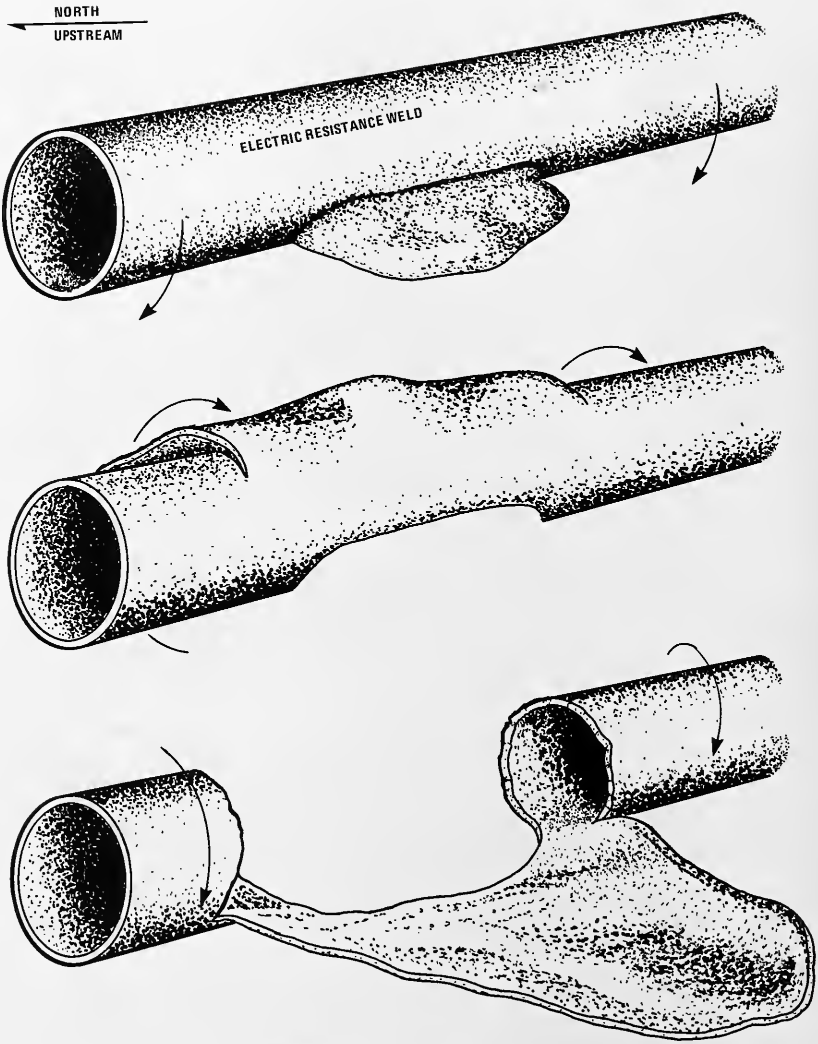


Figure 8. Drawings showing how "flap" was blown out and around the pipe ending up on the west side of the line.

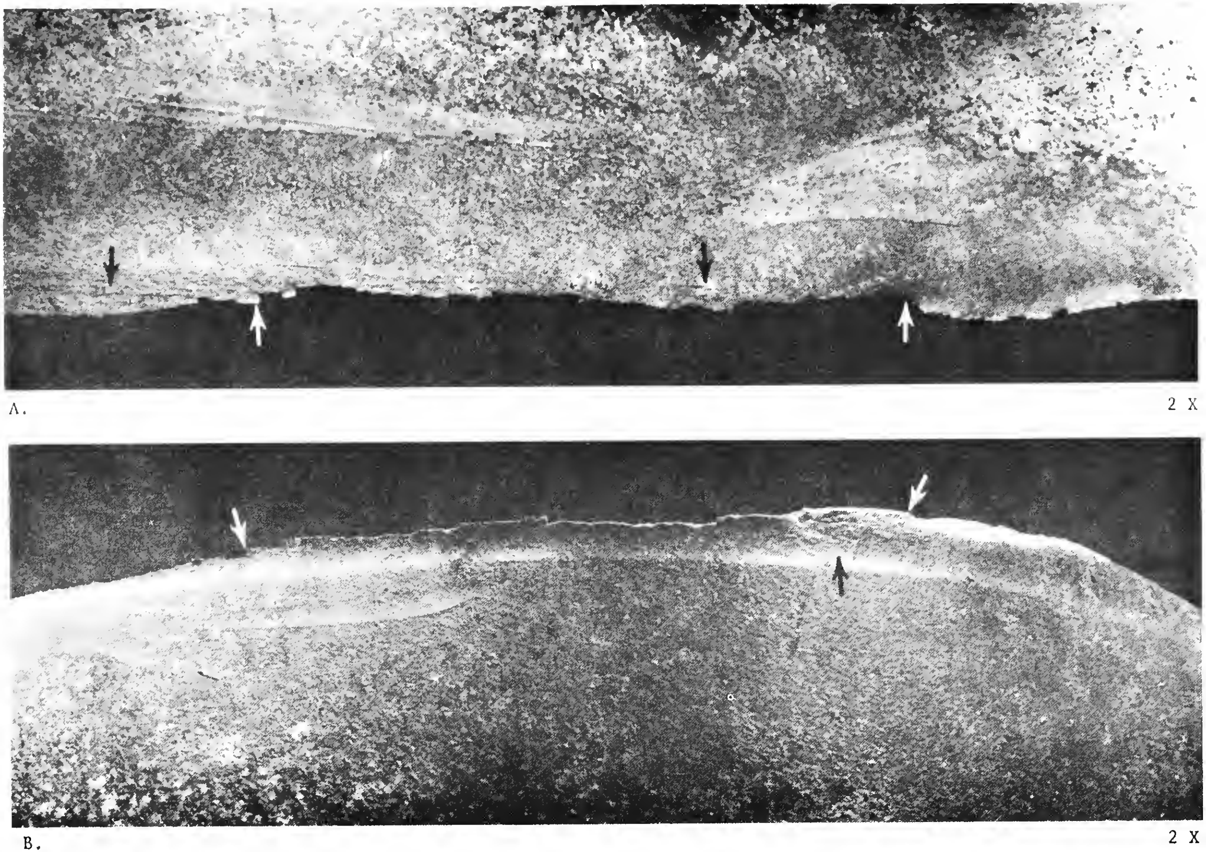
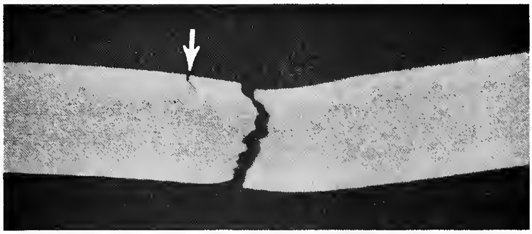
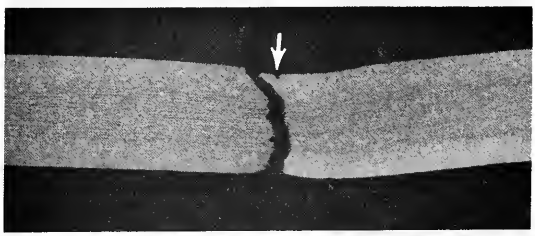


Figure 9. Outside surface showing gouge along the fracture. The white arrows indicate the location of flat fracture; the black arrows indicate secondary cracks.

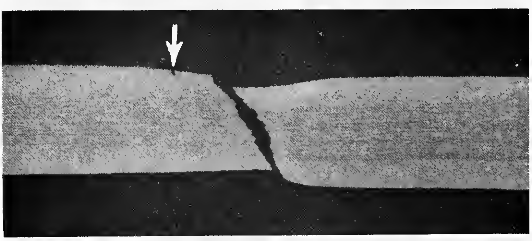
A.



B.



C.



D.

6 X
Nital Etch

Figure 10. Sections across the rupture origin at four locations. A and B are from the right one-third of the origin; C is near the center, and D is near the left end where the fracture was changing from flat to 45-degree shear. The top of the fracture is at left. The arrows indicate secondary cracks.

	North Sample	South Sample	API Requirements For X52
Carbon, percent	0.27	0.26	0.32 Max.
Manganese, percent	1.31	1.32	1.35 Max.
Phosphorus, percent	0.019	0.020	0.04 Max.
Sulfur, percent	0.041	0.043	0.05 Max.
Yield Strength, psi	59,300	60,100	52,000 Min.
Tensile Strength, psig	79,300	78,700	66,000 Min.
Elongation in 2 inches (percent)	23.0	26.0	14.0 Min.

Both samples met the chemical and tensile requirements for API 5LX-52 pipe.

APPENDIX B

REVIEW BY THE LABORATORY SERVICES DIVISION NATIONAL TRANSPORTATION SAFETY BOARD OF THE METALLURGICAL ANALYSIS OF THE FAILED PIPE MID-AMERICA PIPELINE SYSTEM, LIQUEFIED PETROLEUM GAS PIPELINE, RUPTURE AND FIRE, DONNELLSON, IOWA AUGUST 4, 1978

A fractographic analysis of the fractures in the failed pipeline indicated that failure initiated at a location where the pipe was gouged and dented. All the fracture features were typical of an overload failure. There was no evidence to indicate a fatigue or corrosion-related failure. The most probable cause of failure was delayed rupture due to continued creep of the materials at the root of shallow surface cracks which were formed when the pipe was gouged and dented.

This type of failure is common in pressure vessels and pipelines and results in delayed rupture because the flaws in the pipe surface continues to creep and strain with time until a critical condition is reached and failure occurs.

APPENDIX C

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R. S. SINHA FEB. 21, 79. Page 1 of 9
CHECKED BY L. R. CAYES

SYNOPSIS

This analysis was based on the facts obtained during the investigation by the National Transportation Safety Board and the statements given at a subsequent public hearing concerning the Farmington lateral break, MP-33, State Highway 2, Donnellson, Iowa. It has been concluded that the lowering of the pipe produced combined stresses; these stresses, when exerted at a stress concentrator, dent and gouge, were sufficient to cause the pipeline to rupture.

INTRODUCTION

On February 15, 1979, the National Transportation Safety Board requested the Federal Highway Administration (FHWA), Office of Research and Development, to perform a structural analysis of the Farmington lateral break, in Iowa.

The propane pipeline that ruptured on August 4, 1978, had been lowered by a construction crew 3 months before the accident.

The construction history indicated that during the lowering the pipe was allowed to rest on pillars (dykes) that were 3 feet wide, spaced 30 feet apart and was lowered by the side trenching methods--allowing the pillars to collapse under the weight of pipe. Liquid propane was in the pipeline during the lowering process at a static pressure of 200 to 250 psi. The pressure in the pipeline was 1,244 psig at the time of the accident.

Laboratory investigations performed indicated that the pipe had an ultimate stress capacity of 59,300 psi and a rupture stress capacity of 79,100 psi.

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R. S. SINHA FEB. 21, 79. Page 2 of 9
CHECKED BY L. R. CAYES

CRITERIA

The soil between the pillars (dykes) was compacted using standard procedures. Thus the characteristics of the undisturbed soil in the area of the pillars were different from the distrubed soil between the pillars.

During the lowering project the pipeline work was delayed several days due to heavy rains. The rain water probably percolated through the soil pores accentuating the differences in bearing load of the pipeline. The manner in which the pipeline was lowered would cause the pipe to behave as a pipe resting on 18 pillars, spaced 30 feet apart. The support conditions of the pipe at the dykes and at the ends were inbetween the fixed and free conditions. The pipe when backfilled behaved as a beam resting on several supports and lifted itself to the left of point A (see figure 1), thereby directly bearing the load of 4 feet of earth fill which contributed to the failure of the pipe.

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R. S. SINHA FEB. 21, 79. Page 3 of 9
CHECKED BY L. R. CAYES

ANALYSIS

1. Section Properties Of Pipe

External Diameter = D_1 = 8 5/8" = 8.625

Thickness of Pipe Metal= 0.156"

Internal Diameter = D_2= 8.625 - 2 X 0.156 = 8.313"

Area of Cross Section $= \frac{\pi}{4} \times (D_1^2 - D_2^2)$

$= \frac{\pi}{4} (8.625^2 - 8.313^2)$

$= \frac{\pi}{4} (74.39 - 69.11)$

$= \frac{\pi}{4} \times 5.28 = 4.147^{\square}$"

Material Volume/Ft. = 4.147 X 12 = 49.77 in. 3/ft.

Weight of Pipe/Ft. = 49.77 X 0.283 = 14#/Ft.

(Steel weighs 0.283#/in^3)

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R. S. SINHA FEB. 21, 79.
CHECKED BY L. R. CAYES

Internal Volume of Pipe/FT

$$= \frac{\pi}{4} \times D_2^2 \times 12 = \frac{3.14 \times 8{\cdot}313^2}{4} \times 12$$

$$= 651{\cdot}31 \text{ cubic inch/ft.}$$

$$= 651.31 \times 0{\cdot}36 \times 10^{-2} \text{ gallon/ft.}$$

$$= 2{\cdot}4 \text{ gallons/ft.}$$

Weight of Propane

$$= 0{\cdot}423^{\#}/\text{gallons.}$$

Weight of Propane/ft. of pipe

$$= 0{\cdot}423 \times 2{\cdot}4 = 10\#/\text{ft.}$$

Moment Of Inertia

$$MI = \frac{\pi}{64} (D_1^4 - D_2^4)$$

$$= \frac{\pi}{64} (8{\cdot}625^4 - 8{\cdot}313^4)$$

$$= \frac{\pi}{64} (5533{\cdot}97 - 4775{\cdot}63)$$

$$= \frac{\pi}{64} \times 758{\cdot}34$$

$$= 37{\cdot}23 \text{ in}^4$$

$$\text{Section Modulus} = Z = \frac{I}{y} = \frac{37{\cdot}23}{4{\cdot}3125} = 8{\cdot}63$$

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R. S. SINHA FEB. 21, 79. Page 5 of 9
CHECKED BY L. R. CAYES

Calculation Of Stress

a. Due To Lowering of Pipe.

Section Opened 520' ±

Sag = 10' (First EL. = -4
Lowered EL. = -14)

% of Sag to span $= \frac{10}{520} \times 100 = 2\%$ less than 5%

∴ Assumed parabolic lowering than catenary.

Tension due to lowering:

$$T_A = wa \sqrt{1 + \left(\frac{a}{2f_a}\right)^2}$$

$$= 14 \times 260 \sqrt{1 + \frac{260 \times 260}{20 \times 20}}$$

$$= 14 \times 260 \times \sqrt{170}$$

$$= 47{,}460^{\#}$$

Stress due to lowering

$$\frac{TA}{A} = \frac{47460}{4 \cdot 147} = 11{,}444^{\#}/\square''$$

and it remains as residual stress through the life of the pipe.

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R. S. SINHA FEB. 21, 79. Page 6 of 9
CHECKED BY L. R. CAYES

b. Stress Due to Self weight of pipe

(wt. = 14#/ft., span = 30' the distance between dykes)

$$B.\ M = \frac{Wl^2}{10} = \frac{14 \times 30 \times 30 \times 12}{10} = 15{,}120\#''$$

$$Stress = \frac{M}{Z} = \frac{15120}{8.63} = 1752\#/\square'' \longleftarrow (b)$$

c. Stress due to self weight of propane (10#/ft.)

$$= 1752 \times \frac{10}{14} = 1251\#/\square'' \longleftarrow (c)$$

d. Stress due to internal pressure $\left(\frac{PR}{2t}\right)$

P = 1244 psi

$$Stress = \frac{1244}{2}\left(\frac{8{\cdot}625 - {\cdot}156}{2}\right) \times \frac{1}{0{\cdot}156}$$

$$= 16{,}884\#/\square'' \text{ -----------(d)}$$

e. Stress due to earth fill

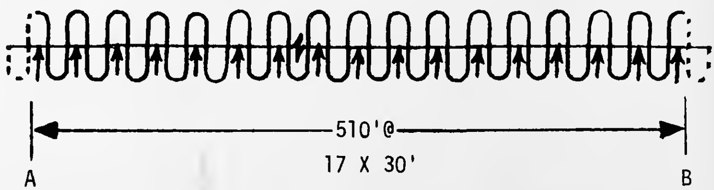


Figure 1.

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R. S. SINHA FEB. 21, 79. Page 7 of 9
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e. Stress due to earth fill cont'd.

Case 1

weight of earth on pipe ⟶ 10' deep X 8" wide
(ignoring the edge effects and arching)

$= {}^{*}130 \times 10 \times \frac{8}{12} = 867^{\#}/\text{ft.}$

*(Note: Weight/Ft. average Iowa condition)

$$\text{B.M.} = \frac{WL^2}{\text{Moment Factor}} = \frac{867 \times 30 \times 30}{10} \times 12$$

$$= 936360''^{\#}$$

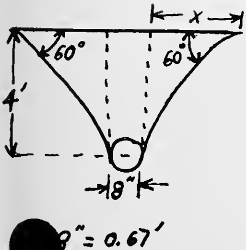
$$\text{Stress} = \left(\frac{M}{Z}\right) = \frac{936360}{8{\cdot}63} = 108{,}500 \text{ psi}$$

Now it is possible that this earth loading tried to lift the pipe to the left of A (Point A shown in Figure 1)

Case 2 (no arching of earth) The earth load is only 4' deep

$\therefore \text{stress} = 108{,}500 \times \frac{4}{10} = 43{,}400 \text{ psi}$ ⟵ (e)

Case 3 Arching of earth included (4' depth)



$x = \frac{4}{\sqrt{3}} = 2.31'$

Area of cross section of earth coming on pipe

$= \frac{1}{2} \times 4 \left(\frac{0{\cdot}67 + 0{\cdot}67 + 2{\cdot}31 + 2{\cdot}31}{}\right)$

$= 2 \times 2{\cdot}98 = 6\square'$

weight per ft. length of pipe $w = 6 \times 1 \times 130 = 780^{\#}/\text{ft.}$

$\text{Stress} = 108{,}500 \times \frac{780}{867} = 97{,}612 \text{ psi}$

much greater than 79,100 therefore the pipe failed.

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R. S. SINHA FEB. 21, 79. Page 8 of 9
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SUMMARY OF STRESSES

a.	Stress due to lowering of pipe	=	11,444 psi	≃31,331 (a–d)
b.	Stress due to self weight of pipe	=	1,752 psi	
c.	Stress due to weight of propane gas	=	1,251 psi	
d.	Stress due to Internal pressure	=	16,884 psi	
e.	Stress due to earth load (Case 2.-no arching)	=	43,400 psi	
	TOTAL		74,731 psi	

Which is much greater than the yield stress of 59,300 psi and much closer to the breaking stress of 79,100.

Case 1 - Stress Concentration factor assumed 3:

Stress due to stress concentration due to presence of flaw (dent)

3 X (43,400 + 1251 + 1752) = 139,209 psi

much greater than 79,100 psi

. . the pipe had to fail.

STRESS ANALYSIS
MID AMERICA PIPELINE SYSTEM, TULSA, OKLAHOMA
FARMINGTON LATERAL BREAK, MP 33 (ST. HWY. 2)

ANALYSIS BY R.S. SINHA FEB. 21, 79. Page 9 of 9
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Case 2. - Stress due to earth fill including arching

31,331 + 97,612 psi = 128,943 psi

Much greater than 79,100 psi

The above caculations represent an order of magnitude of forces imposed upon the pipeline at the time of the accident.

CONCLUSIONS

Based on the criteria used in this analysis it is concluded that the lowering of the pipe produced combined stresses. These stresses, when exerted at a stress concentrator, dent and gouge, were sufficient to cause the pipeline to rupture.

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pipeline rupture and fire,

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