National Aeronautics and Space Administration

Out of Line:

San Bruno Pipeline Explosion

Leadership ViTS Meeting

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THE MISHAP

Peaceful. Typical. Nondescript. These words should have described San Bruno, California on September 9, 2010. But residents of San Bruno's Crestmoor neighborhood will likely recall that day as one of horror and of grief—a day when some of them lost everything. That evening, a disaster of unimaginable destructive force occurred when a gas line erupted into an inferno that reduced the area to rubble. Witnesses likened the scene that followed to a war zone. Some residents narrowly escaped injury and many were hospitalized; others suffered the irrevocable loss of friends and family members. The gas line owner, Pacific Gas and Electric Company (PG&E), estimated the costs of damages at $763 million.

Line 132: Construction

• PG&E is an intrastate natural gas supplier whose customer base sprawls across Northern and Central California. Residents located in the peninsula between the San Francisco Bay and the Pacific Ocean receive service from one of three natural gas transmission lines, including Line 132.

• Line 132 was constructed in phases, starting in 1944, out of 24- to 36-inch, longitudinal welded steel pipe segments bonded together by girth welds. Line 132 entered service in 1948.

• Testing standards for newly fabricated pipe did not exist at the time of its construction; consequently Line 132 was likely installed without undergoing the same pressure tests to which new pipes are subjected today.

• In 1955, the American Society of Mechanical Engineers (ASME) set forth a voluntary national consensus standard that called for transmission lines to undergo rigorous testing prior to entering service. In 1956, PG&E relocated 1,851 feet of Line 132, accommodating construction, but did not test.

Line 132: Operation

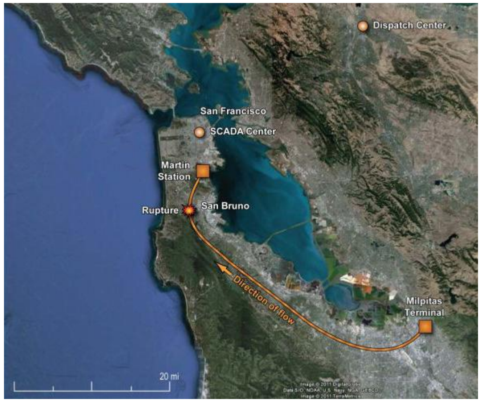
• Stations along gas distribution lines transmit data including pressure, flow, and valve positions to Supervisory Control and Data Acquisition (SCADA) operators.

• The line's outgoing pressure is limited to a certain level by both automated controls, based on a pre-programmed control logic, and remotely by operators at SCADA who can control regulator valves.

• A gas transmission line's maximum *allowable* operating pressure (MAOP), as defined in the Code of Federal Regulations (CFR), varies depending on the properties of the pipe.

• A line's maximum operating pressure (MOP) is limited by the lowest MAOP of any segment connected to that line to create a safety margin.

• Line 132's MAOP was 400 psig, but since Line 132 was also connected to Line 109 (whose MAOP was 375 psig), Line 132's MOP was limited to 375 psig.



Line 132 originates at Milpitas Terminal and ends at Martin Station.

Safety Regulations

• In 1970, new federal regulations required newly constructed gas transmission lines to undergo an extensive pressure test prior to entering service. The results of that test would determine the pipe segment's MAOP.

• A grandfather clause allowed operators to set the MAOP of pipes constructed prior to 1970 at "the highest actual operating pressure to which a segment was subjected during the preceding 5 years," which allowed PG&E to set the MAOP for Line 132 at 400 psig

• In 2004, performance-based regulations passed, allowing pipeline operators to formulate their own integrity management program (IMP), such that they could effectively identify high-consequence areas, recognize potential hazards, address significant threats, and prioritize line segments for testing and mitigation.

WHAT HAPPENED?

Power Replacement and Overpressure

- On September 9, 2010, PG& E technicians were dispatched to the Milpitas terminal to replace electronic systems as part of an upgrade to the station's power supplies.
- Technicians removed power from an unidentified breaker, resulting in an unexpected power loss at a local control panel. PG&E had no contingency for this, so an alternate power source was used which resulted in the transmittal of erratic voltages, triggering more than 60 alarms at SCADA.
- Erratic voltages sent erroneous low-pressure signal to the regulator valves, causing them to open fully.
- Regulator valves could not be controlled due to power loss. Outgoing pressure was solely controlled by monitor valves—the last line of defense against over-pressure.
- At 5:52 pm, SCADA operators informed Milpitas technicians of abnormally high pressure readings, well above the monitor valve limits, and requested that they place a pressure gauge on the line.
- Milpitas technicians reported a line pressure of 396 psig, slightly less than the Maximum Allowable Operating Pressure (MAOP) of 400 psig but well above the Maximum Operating Pressure (MOP) of 375 psig.
- At 6:02 pm, SCADA operators notified another PG&E facility that "we've got a major problem…and we've over pressured the whole peninsula."

Explosion and Fire

- At 6:11pm, emergency dispatchers began receiving 9-1-1 calls regarding a massive explosion and fire.
- PG&E could not identify the rupture site and close the mainline until 7:30pm
- Fires in the area continued for two days after the initial blast.
- A 72-foot long by 26-foot wide crater was pounded into the ground; 8 were killed, 58 were injured, and 108 homes were affected.

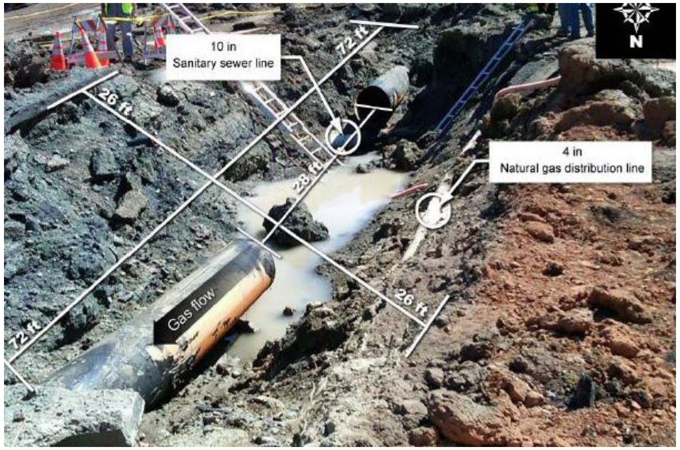


Figure 1: The ruptured segment of pipe, discovered 100 feet away from the crater, was 28 feet long and weighed approximately 3,000 pounds.

PROXIMATE CAUSE

The National Transportation Safety Board (NTSB) issued a report that attributed the explosion to a gas leak from a pipe segment, designated as segment 180, buried 3 feet beneath the intersection of Earl Avenue and Glenview Drive. Investigators discovered the ruptured segment 100 feet away from the crater that marked ground zero. Post-accident inspection revealed that segment 180 contained several shorter lengths with incomplete longitudinal welds—a defect that weakened the pipe's structural integrity and allowed a pre-existing crack in the seam to propagate. When subjected to the 396 psig pressure spike, the pipe ruptured despite the fact that this value still fell within the limits of the line's MAOP of 400 psig. The gas that spewed above ground ignited, decimating a neighborhood, claiming lives, and injuring dozens of residents.

UNDERLYING ISSUES

Poor Quality Control

- The poorly welded seam in segment 180 would have been visible to the naked eye during a 1956 relocation. No record of inspection or testing could be located.
- In 1988, a gas leak was identified in Line 132, 8.78 miles from the rupture site. The leak was attributed to a defect in the pipe's longitudinal seam and 12 feet of pipe were replaced. No record of testing and inspecting of the line for similar flaws was ever located.
- After a deadly 2008 natural gas explosion involving a PG&E distribution line, the NTSB investigation cited inappropriate pipe material as a cause of the accident and made recommendations for improving safety. PG&E did not act on the recommendations before the San Bruno explosion.

Inadequate Integrity Management

- PG&E's Integrity Management Program(IMP) was based on incomplete and inaccurate information about its pipes. Records classified segment 180 as a seamless pipe, but in fact, the segment was composed of seam-welded pipe and contained several shorter lengths of pipes with incomplete longitudinal welds. Furthermore, steel grades, though unknown, were given "assumed" values and no steps to verify and correct the assumed values had taken place.
- PG&E's IMP failed to account for the pipes' design and materials contribution to the risk of failure. It performed assessments without accounting for previously identified cracks in the pipes as threats to structural integrity and used examination methods that could not identify defects in longitudinal or girth welds.
- If overseeing bodies had forced PG&E to correct its records, knowledge of the aging pipe's true properties *may* have prompted PG&E to test and ultimately repair or replace the faulty segment.
- NTSB discovered that PG&E employed a practice that circumvented the goal of the integrity management program: Increasing consumer demand meant increasing outgoing pressure on its lines. Eventually, the increased pressure would exceed the MAOP, forcing PG&E to perform extensive pressure testing. To avoid this requirement, PG&E raised the pressure of its lines once every five years so it could claim exemption from the testing per the grandfather clause.

Flawed Emergency Response

- The NTSB asserts that although a more rapid emergency response on PG&E's part would not have prevented the catastrophe, the effects of the fire would have been significantly reduced.
- PG&E's disorganized response allowed the continuously leaking gas to feed the flames.
- Per NTSB, PG&E should also have formulated emergency procedures, not only for a major event such as the San Bruno explosion, but also for maintenance activities such as the electrical work taking place at Milpitas.
- If PG&E had formulated a plan for controlling the regulator valves during a power surge, the tragic events at San Bruno probably would not have occurred that day.

FOR FUTURE NASA MISSIONS

> "Organizational accidents have multiple contributing causes, involve people at numerous levels within a company (organization), and are characterized by a pervasive lack of proactive measures to ensure adoption and compliance with a safety culture."
>
> -NTSB San Bruno Accident Report

- The tragedy at San Bruno took place because a flaw was built into the system at inception and remained a latent hazard for more than 50 years.
- Although several opportunities to detect and correct that flaw arose, a lack of vigilance and engagement lowered PG&E's defenses until the San Bruno explosion shocked the company into action.
- Lack of perceived safety risk possibly bred comfort with the status quo, for PG&E did not act upon NSTB investigation recommendations after the 2008 explosion. NASA safety audit findings include equipment labeling and other hazards such as PG&E faced. Timely and tireless follow-up to correct the conditions that audits and inspections discover can prevent deadly mishaps.
- When the director of the California Public Utilities Commission (CPUC) consumer protection and safety division discovered this practice, he stated, "artificially raising the pressure in a pipe that has identified integrity seam issues seems to be a wrong-headed approach to safety."

- Despite embracing safety as a core value, NASA is vulnerable to latent hazardous conditions such as those leading to the San Bruno explosion.
- To some degree, the 2010 National Academies' assessment of NASA's basic research capabilities detailed large backlogs of deferred maintenance at NASA research centers. Years of bare subsistence research funding without sustaining infrastructure or procuring new instruments had left laboratory capabilities diminished compared to modern university and corporate laboratories. The study found that systems designed for planned maintenance are instead being run to failure.
- Separately, on construction and demolition projects, latent high-energy hazards such as buried conduits are struck inadvertently. Lack of accurate drawings along with failure to verify a circuit as de-energized contributed to a near-fatal electric shock at a NASA Center demolition site.
- To carry forward the NASA tradition of leadership in exploration and scientific endeavors, we must feed our motivation to discover those latent conditions—known and unknown, sometimes in combination—that lead to errors and unsafe situations; this is a learning culture transformed into an engaged culture, where we all do our part.