GRI-96/0385

Topical Report

Natural Disasters and the Gas Pipeline System

Prepared by:
Risk & Industrial Safety Consultants, Inc.
Des Plaines, Illinois

Stan Martin & Associates
Redwood City, California

Gas Research Institute

Environment and Safety Business Unit
November 1996

RISC No. 4038.3

NATURAL DISASTERS AND THE GAS PIPELINE SYSTEM

Topical Report

Prepared by

Risk & Industrial Safety Consultants, Inc.
292 Howard Avenue
Des Plaines, IL 60018-1906

and

Stan Martin & Associates
860 Vista Drive
Redwood City, CA 94062

Submitted to

Environment and Safety Department
Gas Research Institute
8600 W. Bryn Mawr Avenue
Chicago, IL 60631

GRI Contract Number: 5092-252-2569
Modification No. 3

November 15, 1996

RISC

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50272-101

PB97-129282

REPORT DOCUMENTATION PAGE	1. REPORT NO. GRI-96/0385	2.	3.
4. Title and Subtitle NATURAL DISASTERS AND THE GAS PIPELINE SYSTEM			5. Report Date November 15, 1996 6.
7. Author(s) S. Atallah, S. Saxena, S.B. Martin, A.B. Willowby & R. Alger			8. Performing Organization Rept. No. 4083.3
9. Performing Organization Name and Address Risk & Industrial Safety Consultants, Inc. 292 Howard Avenue Des Plaines, IL 60631			10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) 5092-252-2569 Mod. 3 (G)
12. Sponsoring Organization Name and Address Gas Research Institute 8600 W. Bryn Mawr Avenue Chicago, IL 60631			13. Type of Report & Period Covered Topical Report August 1994-June 1995 14.

15. Supplementary Notes

Subcontractor: Stan Martin & Associates, 860 Vista Drive, Redwood City, CA 94062

16. Abstract (Limit: 200 words)

Episodic descriptions are provided of the effects of the Loma Prieta earthquake (1989) on the gas pipeline systems of Pacific Gas & Electric Company and the City of Palo Alto and of the Northridge earthquake (1994) on Southern California Gas' pipeline system. The emergency response plans and activities of South Carolina Electric & Gas Company during hurricane Hugo (1989) and of City Gas Company of Florida and other small gas companies during hurricane Andrew (1992) are also reviewed. Descriptions of the Great Flood of 1993 and its effects on the operations of Iowa-Illinois Gas & Electric Company and Laclede Gas Company and of the San Jacinto River Floods on the transmission lines of Valero Gas Co. are also provided. Local and federal regulatory requirements, and the current practices by the gas industry for dealing with natural disasters, such as through preventive measures (e.g., strapping of water heaters, excess flow valves), and the tracking of weather-related events are described. The important role that preplanning and coordination with the local emergency response bodies and other gas utilities plays during a natural disaster is examined.

17. Document Analysis a. Descriptors

Natural Gas Pipeline System, Natural Disasters, Earthquakes, Hurricanes, Floods, Natural Gas Distribution System, Transmission, Fires, Emergency Planning, Response

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited Distribution	Unclassified	106
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

RESEARCH SUMMARY

Title	**NATURAL DISASTERS AND THE GAS PIPELINE SYSTEM**
Contractor	Risk and Industrial Safety Consultants, Inc. GRI Contract No. 5092-252-2569
Sub-Contractor	Stan Martin & Associates
Authors:	Sami Atallah, Sara Saxena, Stanley B. Martin, A. B. Willowby and Raymond Alger
Report Period	August 9, 1994 - June 1, 1995 (Topical Report)
Objectives	The objectives of this study were to assemble factual information on the experiences of the gas industry and response agencies during selected major natural disasters that may have compromised the gas distribution and transmission pipeline systems and to evaluate the effectiveness of public and gas company emergency response plans to such disasters.
Technical Perspective	During the past few years, a number of high severity natural disasters impacted well-populated communities in various parts of the United States. These events include the Loma Prieta/San Francisco Bay earthquake of October 17, 1989, the more recent earthquake of January 24, 1994, with an epicenter in Northridge north of Los Angeles, the flooding of the Mississippi river and the Midwestern states during the summer of 1993, the San Jacinto River flood in Texas during October 1994, hurricane Hugo that devastated St. Croix, Puerto Rico and the coastal areas of South Carolina in September 1989, and hurricane Andrew that swept through southern Florida in August 24, 1993 with wind speeds of up to 175 mph. Tornadoes have also been a frequent menacing visitor to communities in the Midwestern and Southeastern states. In most of these events, lifelines to the community were severely disrupted. Among these lifelines, the gas transmission and distribution pipeline systems were sometimes breached either underground or at connections to household appliances. The relative contribution of the escaping gas to the overall damage resulting from major natural disasters is not well documented. The hazard presented by escaping natural gas may be relatively small when one considers the overall damage of a high magnitude earthquake or a hurricane. On the other hand, escaping gas may have impeded rescue and

response operations and limited access to certain areas. Also, it may have contributed to the severity of any fires or explosions that may have followed the natural event.

Results

Episodic descriptions are provided of the effects of the Loma Prieta earthquake (1989) on the gas pipeline systems of Pacific Gas & Electric Company and the City of Palo Alto and of the Northridge earthquake (1994) on Southern California Gas' pipeline system. The emergency response plans and activities of South Carolina Electric & Gas Company during hurricane Hugo (1989) and of City Gas Company of Florida and other small gas companies during hurricane Andrew (1992) are also reviewed. Descriptions of the Great Flood of 1993 and its effects on the operations of Iowa-Illinois Gas & Electric Company and Laclede Gas Company and of the San Jacinto River Floods on the transmission lines of Valero Gas Co.are also provided. Local and federal regulatory requirements, and the current practices by the gas industry for dealing with natural disasters, such as through preventive measures (*e.g.*, strapping of water heaters, excess flow valves), and the tracking of weather-related events are described. The important role that preplanning and coordination with the local emergency response bodies and other gas utilities plays during a natural disaster is examined.

Technical Approach

Data were collected from a number of gas companies that were directly affected by natural disasters in recent years. SM&A devoted its effort to the California earthquakes while RISC concentrated on hurricanes in the East Coast and floods in the Midwest and Texas. The team collected press releases and newspaper reports from various local sources. Technical papers presented by the gas industry, public reports prepared by various organizations such as the Federal Emergency Management Administration, the Red Cross, the National Institute for Standards and Technology, and the Association of Bay Area Governments and internal reports prepared by the gas industry were reviewed.

Project Implications

The behavior of natural gas distribution and transmission systems during natural disasters is of great interest not only to the gas industry, but also to regulatory bodies and emergency response agencies who are concerned with public safety. Learning from past events is a recognized, cost effective approach for developing strategies for dealing with similar future events and for identifying gaps in knowledge that require additional studies or research by the gas industry.

Ted A. Williams
GRI Project Manager

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1.0 INTRODUCTION

1.1 BACKGROUND

During the past few years, a number of high severity natural disasters impacted well-populated communities in various parts of the United States. These events include the Loma Prieta/San Francisco Bay earthquake of October 17, 1989, the more recent earthquake of January 24, 1994, with an epicenter in Northridge north of Los Angeles, the flooding of the Mississippi river and the Midwestern states during the summer of 1993, the San Jacinto River flood in Texas during October 1994, hurricane Hugo that devastated St. Croix, Puerto Rico and the coastal areas of South Carolina in September 1989, and hurricane Andrew that swept through southern Florida in August 24, 1993 with wind speeds of up to 175 mph. Tornadoes have also been a frequent menacing visitor to communities in the Midwestern and Southeastern states. In most of these events, lifelines to the community were severely disrupted. Among these lifelines, the gas transmission and distribution pipeline systems were sometimes breached either underground or at connections to household appliances.

The relative contribution of the escaping gas to the overall damage resulting from major natural disasters is not well documented. The hazard presented by escaping natural gas may be relatively small when one considers the overall damage of a high magnitude earthquake or a hurricane. On the other hand, escaping gas may have impeded rescue and response operations and limited access to certain areas. Also, it may have contributed to the severity of any fires or explosions that may have followed the natural event.

The behavior of natural gas distribution and transmission systems during natural disasters is of great interest not only to the gas industry, but also to regulatory bodies and emergency response agencies who are concerned with public safety. Answers are needed to such questions as:

- Based on previous experience, which components of a gas distribution and transmission systems are likely to fail and which parts are likely to survive during an earthquake, a flood or a hurricane?
- Are steel pipe distribution systems more vulnerable than plastic pipe?
- What was the impact of gas release during major natural events?
- What happened to gas piping systems at river crossings during a major flood ?
- How did responding agencies and the gas industry deal with the compromised gas distribution and transmission systems? Did the escaping gas interfere with emergency response and rescue operations?
- What was done by the gas industry to return to normalcy?

The answers to these and many other questions about the behavior of natural gas distribution and transmission systems during natural disasters can only be found by collecting information and reviewing what happened during actual historic events. Learning from past events is a recognized cost effective approach for developing strategies for dealing with similar future events and for identifying gaps in knowledge that require additional studies or research by Gas Research Institute and the gas industry.

1.2 OBJECTIVE

The objective of this study was to assemble factual information about the experiences of the gas industry and response agencies during selected major natural disasters that may have compromised the gas distribution and transmission systems and to identify the lessons learned from such disasters.

1.3 APPROACH

To achieve this goal, Risk & Industrial Safety Consultants, Inc. (RISC), together with its subcontractor Stan Martin and Associates (SM&A), collected data from a number of gas companies that were directly affected by natural disasters in recent years. SM&A devoted its effort to the California earthquakes while RISC concentrated on hurricanes in the East Coast and floods in the Midwest and Texas.

The research team also collected press releases and newspaper reports from various local sources. Technical papers presented by the gas industry at conferences such as A.G.A. meetings and reports prepared by various organizations such as the Federal Emergency Management Administration, the Red Cross, the National Institute for Standards and Technology, the Association of Bay Area Governments were reviewed.

1.4 REPORT CONTENTS

Chapter 2 contains brief descriptions of the major natural disasters of concern and their effect on the gas pipeline system. In Chapter 3, the current preventive and protective practices used by the gas industry and any applicable standards are reviewed. Chapter 4 deals with the lessons learned from past disasters and the recommendations made by the gas industry for improved operation during natural disasters. Chapter 5 is a list of references. Several appendices are provided.

1.5 ACKNOWLEDGMENTS

This report could not be prepared without the help and contributions made by a number of individuals at various companies and response agencies. The authors specifically wish to thank the following companies and their representatives for making available the information cited in this report:

City Gas Company, Miami, FL (Mr. Douglas Baumgartner)
Florida Power and Light Company, Miami, FL (Mr. Edward Zillioux)
Indiantown Gas Company, Indiantown, FL (Mr. Brian Powers)
Iowa-Illinois Gas and Electric Company, Bettendorf, IA (Mr. Fred Attwood)
Laclede Gas Company, St. Louis, MO (Mr. Harry Haury)
Mississippi River Transmission Corporation, St. Louis, MO (Mr. Frank Antoin)
Palo Alto Gas Utilities, Palo Alto, CA (Mr. Robert Gross)
Panhandle Eastern Corporation, Houston, TX (Mr. Jim Hart)
Peoples Gas System, Inc., Tampa, FL (Mr. Mike Farmer)
South Carolina Electric and Gas Company, Charleston, SC (Mr. Dan Kassis)
South Florida Natural Gas Company, New Smyrna Beach, FL (Mr. John W. McClelland)
Valero Natural Gas Company, San Antonio, TX (Mr. Gary Spangler)

Special mention should be made of the contributions made by the engineering staff of Pacific Gas and Electric Company, San Francisco, and Southern California Gas Company, Los Angeles, CA. These companies shared with us valuable information and data that were generated soon after the two earthquakes that severely affected their respective operations.

While performing this study, the authors could not help but be highly impressed by the dedication of all employees of the affected gas distribution companies, and their heroic efforts in responding to public needs during highly stressful and dangerous times. Gas company personnel had to work for many hours, away from their own families, under hazardous conditions, often risking their own safety in the process.

2.0 EFFECTS OF NATURAL DISASTERS ON THE GAS PIPELINE SYSTEM

2.1 EARTHQUAKES

Severe earthquakes are very likely to damage fuel-gas systems and to result in gas releases to the atmosphere, both inside and outside buildings. Since major earthquakes are often followed by fires, there is concern that the released gas may contribute significantly to the damage and life loss due to the fires following earthquakes. Even when viewed superficially, the mechanisms of earthquake damage to fuel-gas systems are obvious. Ground motion during an earthquake can deform and strain pipelines buried in the ground to the point of rupture. The movement of buildings relative to the ground, and relative to the building contents can overturn gas appliances and shear off gas services. Should the building fail structurally, gas piping may rupture within the building at points of high structural deformation. Release of gas within a building can result in a confined gas/air explosion, having the potential to cause more damage and injury than if ignited outdoors. Besides the threat to life and property resulting from gas fires and explosions, failure of natural gas systems during earthquakes can result in extensive, long-term outages of gas supply which can be life threatening and certainly of more impact on the affected communities than just the inconvenience and discomfort.

During the 20th century, in which natural gas systems have come into general, widespread use, there have been numerous examples of earthquake damage to gas systems. Far fewer instances, however, show a clear implication of gas leakage as a contributing factor in post earthquake damage and life loss. The San Francisco earthquake of 1906 occurred at a time when gas lighting was commonly used. There were unconfirmed reports that many of the fires that caused so much of the damage to San Francisco were started by gas lights. The Long Beach earthquake of 1933 (local magnitude of 6.3) resulted in more than one hundred main breaks in the City of Long Beach gas distribution system and the Southern California Gas Company pipeline system had five major and ten minor breaks in the company's welded steel transmission mains [1]. Other damage to the Long Beach gas system included over 2,500 service breaks either below ground at the elbow or at their connections to the mains.

Other California earthquakes in which significant gas system failures occurred and in which gas had the potential of contributing to damage and/or life loss were the Kern County earthquakes of 1952 (magnitude of 7.7) and 1954, and the San Fernando-Sylmar earthquake (magnitude 6.4) of 1971. For purposes of the present report, attention was limited to the two most recent major earthquakes: the Loma Prieta earthquake of October 1989 and the Northridge earthquake of January, 1994.

The Northridge earthquake caused much greater and more extensive damage to fuel-gas systems than did the Loma Prieta earthquake. Accordingly, a more detailed and structured presentation of consequences is provided for the Northridge event.

2.1.1 The Loma Prieta Earthquake

2.1.1.1 Gas Companies Serving the Loma Prieta Earthquake Area

The region affected by the Loma Prieta earthquake was the San Francisco Bay Area and several counties south of it. This region is served by two gas companies:

1. Most of the area is served--as is most of northern California--by Pacific Gas & Electric Company (PG&E), a public utility which is regulated by the State of California. Natural gas is supplied by the Pacific Gas Transmission Corporation. PG&E provides gas and electricity to a 94,000-square-mile region of northern and central California. The company serves more than 4 million electrical customers and more than 3.2 million gas customers. There are 5,324 miles of transmission piping within the system, and 32,647 miles of distribution piping.

2. A municipal gas utility which serves the city of Palo Alto, draws its gas from much the same ultimate sources, through much the same transmission system as that supplying the PG&E services. Roughly 40% of the natural gas supply for this area comes from the north, mainly from Canadian sources, 40% from El Paso Natural Gas from the south, while the remainder is supplied from California fields. Palo Alto buys its gas from Shell Canada. The supply is provided at four stations near the city limits by PGT and PG&E pipelines. There are no high-pressure transmission lines within the Palo Alto system.

2.1.1.2 Effects of the Loma Prieta Earthquake

The magnitude 7.1 Loma Prieta earthquake occurred at 5:04 p.m. PDT on 17 October 1989. It was felt over an area of approximately 400,000 square miles, from Los Angeles in the south to the Oregon-California State Line in the north, and to western Nevada to the east. Its hypocenter was located at 37°02' N latitude, 121°53' W longitude, about 11 miles beneath the Santa Cruz Mountains. This locates the epicenter about 60 miles southeast of San Francisco, 30 miles south of the city of San Josė and 10 miles east-northeast of the city of Santa Cruz. Its seismic-wave energy (2×10^{22} ergs) was about the same as that released in a 500-kT nuclear explosion. Its duration was about 15 seconds, and during that period, more than $6 billion in property damage was inflicted, including major disruptions to utilities, communication and transportation systems. Sixty two lives were lost, 3,757 people were injured, and 12,000 left homeless for periods of up to a month or more [2].

Much of the structural damage caused by the Loma Prieta earthquake resulted from surface ground motion. Liquefaction was common, particularly on artificial, sandy fills. This is a phenomenon which occurs when seismic shear waves having high acceleration and long duration pass through a saturated sandy soil. The granular structure of the soil is so distorted that some of the void spaces collapse. For a short while the soil behaves like a fluid.

There were many instances of landslides and lateral spreading. The highest concentration of building damage occurred in San Francisco's Marina District, where several private residences collapsed, and in the predominantly commercial area south of Market Street.

In the Marina district, sand boils that erupted into basements, streets, and open areas, along with numerous lateral spreading surface cracks showed the extent of liquefaction. Vulnerable building design contributed substantially to the severity of the damage. Most of the breaks in underground utilities, which interrupted gas and water supplies to the Marina, are believed to have resulted from lateral spreading surface cracks. Substantial damage also occurred on the east side of San Francisco Bay in regions of sandy fill. Port facilities suffered extensive damage from both compaction and lateral spreading. Failure of Oakland's Cypress Street viaduct on the east-side of the Bay, where much of the Loma Prieta life loss occurred, was an example of elevated roadway collapse, dramatically comparable to the failure of a span of Bay Bridge between San Francisco and Oakland. Much closer to the epicenter, in Los Gatos, Santa Cruz, and Watsonville, as well as in the rural/suburban areas of the Santa Cruz Mountains, damage was widespread, some of it due to landslides.

In the aftermath of the Loma Prieta earthquake, there were no reports of major damage to the transmission and distribution natural gas pipe line system. Some isolated failures were reported in local distribution piping in the East Bay communities, in the epicentral area and, as noted earlier, in the Marina district of San Francisco. These failures undoubtedly fueled some of the fires that immediately followed the main shock, but there is no evidence that they were responsible for starting the fires.

The high pressure gas-distribution lines in the Marina District were damaged at the miter joints located near the boundary of hydraulic fill and the 1857 shoreline. The high pressure mains were constructed mostly of Grade B steel with electric-arc girth welds. In contrast to the high-pressure (approx 200 kPa, 3 psi) lines, the low-pressure (approx 2 kPa, .03 psi) gas mains were substantially damaged. After the earthquake, approximately 13.6 km of steel and cast-iron mains, ranging from 4 to 12 inches (100 to 300 mm) in diameter were replaced within this area. Roughly half of the damaged pipe was replaced with medium-density polyethylene (MDPE) pipe that was inserted through existing steel and cast-iron pipes. The other half was replaced by direct burial of MDPE piping.

One of the major characteristics of the Loma Prieta earthquake was its effect on transportation systems. This was due mainly to damage to bridges, viaducts, and freeway overpasses and off-ramps. Of the three commercial airports serving the area (San Francisco, San Jose, and Oakland) only SFO was closed down for a period of about 12 hours.

Numerous scattered fires followed the Loma Prieta main shock. In San Francisco, there were 27 structural fires reported immediately, and more than 500 were reported during the seven-hour period after the initial shock. Many off-duty firemen responded during this same emergency period, adding at least 300 extra fighters in the Bay Area, alone. Thus, the number of personnel available for fire fighting was approximately doubled for the early post shock demands. The most serious incident occurred in the Marina district at the intersection of Divisidero and Jefferson. Other structural fires were reported at Cole Street, Larkin and Fulton, and Gough and Sacramento streets in downtown San Francisco. Other fires included a structural fire at a lumber yard, which originated in piping breaks connected to a propane fueled emergency generator, a structural fire on Bixby Street that resulted in the loss of two homes, and two reported fires and a large fuel spill at the San Francisco International Airport. Three engines, two trucks, and a battalion chief were dispatched to the airport from Battalion 10, thus reducing the battalion's strength.

Outside San Francisco, a few fires were reported in the East Bay and in Santa Cruz county. Berkeley had one major fire in a one-story auto service building. That fire was probably due to the ignition of solvents, but it required the response of the entire Berkeley fire department. Oakland did not experience any structural fires. Santa Cruz County reported some two dozen buildings destroyed by fire. In the city of Santa Cruz, one structural fire in a single family residence destroyed the whole building.

Information concerning natural gas leaks on the customers' side of the meter is less well documented, since the gas company seldom records these data. In the Loma Prieta earthquake, much of this type of information was limited to that provided by after-the-event questionnaires filled out by employees of the Mountain Fuel Supply Company, which assisted PG&E by sending 31 of its Customer Service Department personnel to work at restoring service to three communities west of San Jose: Los Gatos, Mountain View and Cupertino. These questionnaires involved a sample of about 18 percent of the affected customers in these three communities. The following significant findings were derived.

1. Nearly 80 percent of buildings had gas valves closed needlessly by the occupants, because these buildings were found to have experienced no gas pipe or appliance damage. Thus, a large proportion of the cases of service interruption were simply precautionary and, in hindsight, unnecessary.

2. Only in Los Gatos, where the Modified Mercalli Intensity (MMI) was equal to VIII, did older buildings (*i.e.*, pre-1950 construction) constitute the majority of buildings that sustained gas-line or gas-appliance damage. See Table 2.1 for a description of the Modified Mercalli Intensity Scale. Elsewhere, a significant fraction of the buildings sustaining such gas-system damage were of newer construction, implying a lack of dependence of such damage on age.

3. The most common form of damage was dislocation of unanchored vent piping. The second most common event involved water heater movement. Damage to piping that was not associated with water heaters was observed in only nine percent of gas-system failures.

4. Natural gas-caused fire damage was estimated at 1 percent or less of the buildings visited. It can be assumed that these were minor fires.

TABLE 2.1: MODIFIED MERCALLI INTENSITY SCALE*

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frames creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken, knickknacks, books etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D[†] cracked. Small bells ring (church, school). Trees, bushes shaken (visible, or heard to rustle).

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

TABLE 2.1: MODIFIED MERCALLI INTENSITY SCALE* (Continued)

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks to canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

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*Source: Richter, C. F., 1957, Elementary Seismology, W. H. Freeman Co., San Francisco, CA.

†Note: To avoid ambiguity, the quality of masonry, brick, or other material is specified by the following lettering system. (This has no connection with the conventional classes A, B and C construction.)

Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B: Good workmanship and mortar; reinforced, but not designed to resist lateral forces.

Masonry C: Ordinary workmanship and mortar; no extreme weaknesses, like failing to tie in at corners, but neither reinforced nor designed to resist horizontal forces.

Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

2.1.2 The Northridge Earthquake

2.1.2.1 Gas Companies Serving the Northridge Earthquake Area

Much of Southern California, including all of the area affected by the Northridge quake, is served by the Southern California Gas Company (SoCalGas), a California state-regulated public utility. SoCalGas' pipeline system is the Nation's most extensive natural-gas transmission, distribution, service and underground storage system. This system serves 4.8 million customers through more than 3,000 miles of transmission pipe (all steel) and 85,000 miles of distribution pipe (60% steel and 40% plastic). Although there is no cast iron pipe in SoCalGas' system, many cast iron valves are still used within the distribution pipeline.

2.1.2.2 Effects of the Northridge Earthquake

The Northridge earthquake occurred on January 17, 1994, at 4:31 a.m. This magnitude 6.7 earthquake was felt throughout Southern California. The hypocenter was about one mile south of Northridge, at a depth of about 9 to 12 miles. It occurred on a thrust fault rather than a slip fault, generating more of the violent up and down motion that inflicts the greatest damage to structures. The areas most impacted by the earthquake included Northridge, Valencia, Simi Valley, Fillmore and Santa Monica.

According to Reference [1], "*...maximum seismic intensities of MMI VIII to IX were assigned to areas totaling approximately 750 km² (290 sq miles) in the San Fernando Valley, Sylmar, Santa Monica, and Fillmore. Maximum horizontal ground acceleration exceeded 1 g in the epicentral area at several permanent stations. Duration of strong ground shaking (peak horizontal acceleration greater than 0.1 g) in the epicentral area was approximately eight seconds.*"

This earthquake, though not as strong as the 1989 magnitude 7.1 Loma Prieta earthquake, affected more people and caused more damage because it occurred in a heavily populated area. The hypocenter of the Northridge quake was directly beneath a suburban area consisting of houses, apartment buildings, shopping malls, hospitals, schools, and a university campus [3].

"*The impact on the built environment was high. Many two and three-story apartment buildings collapsed or were severely damaged. Hundreds of single-family homes suffered minor, but disruptive damage. Several large commercial buildings collapsed. Hundreds of shops and offices were closed because of nonstructural damage such as fallen ceiling tiles and broken glass. Several hospitals were forced to evacuate their patients. The entire Los Angeles County school system was shut down to allow for cleanup and damage repair. Eight large public parking garages suffered partial or complete collapse. Seven major highway bridges were severely damaged or destroyed by the shaking. Water mains broke and flooded streets; gas lines broke and in some instances started significant fires. The entire Los Angeles area lost electric power.*

The normal functioning of the Los Angeles area was significantly disrupted by the highway overpass failures. Most people in the area depend on personal automobiles for transportation; the public transportation capacity is not as sizable as in large cities elsewhere in the country."[3]

The Northridge earthquake resulted in 57 deaths and 8,700 injuries. Approximately 12,000 dwellings were damaged or destroyed and another 16,000 rendered uninhabitable. Preliminary damage estimates, which ranged from $15-30 billion, indicated that the Northridge earthquake was one of the most costly natural disaster in US history. Fortunately, January 17 was a federal holiday (Martin Luther King's Birthday). Because of this and the early morning hour, most nonresidential buildings were empty and traffic was light. This helped limit the number of deaths and injuries.

The damage inflicted on SoCalGas' pipeline system by the Northridge earthquake is summarized in Table 2.2.

2.1.2.3 Transmission Piping System Leaks/Failures

In the 3,100 miles of the transmission pipeline system only 35 leaks were found which amounts to about 11 leaks per 1,000 miles of pipe. The details of these leaks are given in Table 2.3. It can be seen that twenty five of the leaks occurred in one line (No. 1001), and "*...24 of these occurred in oxy-acetylene girth welds of mid-1920s vintage pipe....*"[4] However, it should be noted that "*..older oxy-acetylene welds are not all necessarily bad joints. The filler metal and metallurgical factors are not significantly different from current standards, but the workmanship appears to be the factor accounting for their weakness.*"[4]

A performance analysis of high-pressure gas transmission lines, both during the Northridge earthquake and during previous earthquakes in Southern California has been recently conducted. The results of this study were summarized by the authors in the following paragraphs:

"A detailed and systematic review of the seismic performance of gas transmission lines prior to the 1994 Northridge earthquake shows that all repairs in pipelines affected by traveling ground waves occurred in areas which experienced seismic intensities of MMI ≥ VIII. A review of gas transmission line performance during the 1994 Northridge earthquake discloses a similar pattern of seismic response. Approximately 91% of all pipeline damage caused by traveling ground waves in the 1994 event occurred in areas with MMI ≥ VIII. The earthquake-related damage has been predominantly in the form of ruptures at oxy-acetylene girth welds. The potential for damage in such welds appears to increase considerably for seismic intensities equal to and greater than MM VIII."

"The type of pipeline most vulnerable to earthquake effects is the pre-WWII oxy-acetylene welded pipeline. Eighty-two percent of all earthquake-related repairs were caused by traveling ground wave effects in oxy-acetylene girth welded lines. The preponderant form of damage was rupture at the oxy-acetylene welds, which often are characterized by defects such as poor root penetration, lack of good fusion, and overlapping and undercutting at the toe."

TABLE 2.2: NORTHRIDGE EARTHQUAKE EFFECTS ON THE NATURAL GAS PIPELINE SYSTEM AND RELATED DAMAGE

PIPING SYSTEM LEAKS/FAILURES	Number
TRANSMISSION [4]	35
DISTRIBUTION (Non-corrosion)[4]	
PLASTIC	27
STEEL MAINS	80
STEEL SERVICES	74
STEEL TOTAL	154
DISTRIBUTION (Corrosion)[4]	
METAL PIPE	536
MSA[a]	6,461
BEYOND THE MSA[b]	15,021
CUSTOMER OUTAGES/RESTORES	
OUTAGES	151,000 [5]
RESTORES	122,886 [4], 119,600 [5]
DAMAGED/UNAVAILABLE	31,400 [5]
RESTORES DUE TO:	
LEAKS/DAMAGE	15,021 [4]
VALVE TURNED OFF	107,865 [4]
GAS-RELATED FIRES	
STRUCTURE FIRES[c]	51 [4], 30-50[e] [3], 30-50 [6]
COMPLETELY DESTROYED	23 [4]
PARTIALLY DAMAGED	28 [4]
STREET FIRES[d]	3 [4, 6]
MOBILE HOMES FIRES	
COMPLETELY DESTROYED	172 [4], 111 [6]
EARTHQUAKE VALVES [4]	
RESTORES ATTRIBUTED TO EARTHQUAKE VALVE CLOSING DUE TO EARTHQUAKE[f]	841
NO. WITH LEAKAGE/DAMAGE	162
NO. WITH NO LEAKAGE	679
NUMBER OF EARTHQUAKE VALVES FOUND MALFUNCTIONING[g]	38

NOTES FOR TABLE 2.2

GENERAL COMMENTS:

-- "*Many of the numbers* ....(shown in this table under References. [4 and 5]),.... *which constitute the great majority of the data, should not be considered an exact tally but rather an indication of the magnitude of the situation. The numbers were collected at a time when fixing leaks and restoring service was the primary goal and documenting exact causes of leaks was either of secondary importance or impossible because of the circumstances.*"[4]

-- "*Not all "leaks" should be construed as posing an imminent hazard. Many of the leaks on MSA's and on various appliance connectors were very small volume leaks. In many cases these leaks were found with the use of sensitive gas detection instruments (FI or Gas-Trac Units) and may have existed prior to the earthquake.*"[4]

FOOTNOTES:

a. *MSA* means the meter set assembly

b. *Beyond the MSA* means on the customer's side of the MSA, *i.e.*, on the customer's facility

c. Natural gas-related structural fires caused by gas leakage or associated with gas appliances (non-mobile home related)

d. Fires at Balboa and Rinaldi, Fillmore, and Santa Monica

e. Reference [3] first noted that about 100 fires resulted from the rupture of gas lines without describing what structures or objects were involved in the fire. This was later clarified by noting that there were an estimated 30 to 50 significant fires and these were confined to the building of origin. Thus it is assumed that they correspond to the structure fire category and do not include mobile homes.

f. Means number found on customers property.

g. Means not closed completely, or would not reset.

TABLE 2.3: TRANSMISSION PIPELINES AFFECTED BY THE 1994 NORTHRIDGE EARTHQUAKE

Line No.	Location	Date Installed	Nom. Pipe Dia. Flange Size	Wall Thickness	SMYS (ksi)	MAOP (psig) Flange Class	Actual Op. Pres. (psig)	Break Information
85	MP 90.24	1931	26"	0.250″	33	360	250	Cracked weld
	MP 131.58	1931	26"	0.250″	33	317	205	" "
	MP 150.42	1931	8"WN flange	--	--	CL 300	215	Flange leak
85.02	MP 0.00	1931	12"WN flange	--	--	CL 300	215	Flange leak
85.03	MP 0.04	1931	12"LJ flange nipple	0.380″	64 tensile	317	215	Tension failure
	MP 0.42	1931	12"WN flange	--	--	CL 300	215	Flange leak
104	AlisoCanyon	1941	10″	0.203'	24	228	200	Buckle and split
119	MP 61.07	1930	12″slip-on flange		--	CL 300	215	Flange leak
120	MP 92.59	1930	22"	0.281″	35	228	170	Compress.failure
	MP 92.76	1930	22″	0.281″	35	228	170	Tension failure
1001	MP 28.38	1925	12″	0.220″	25	345	245	Tension failure
	MP 36.13	1925	12″	0.220″	25	345	245	" "
	MP 37.09	1925	12″	0.220″	25	345	245	" "
	MP 37.10	1925	12″	0.220″	25	345	245	" "
	MP 40.52	1925	12"	0.220″	25	345	245	" "
	MP 40.58	1925	12″	0.220″	25	345	245	" "
	MP 40.59	1925	12″	0.220″	25	345	245	" "
	MP 41.80	1925	12″	0.220″	25	345	245	" "
	MP 41.80	1925	12″	0.220″	25	345	245	Compress.failure
	MP 41.95	1925	12″	0.220″	25	345	245	Tension failure
	MP 41.95	1925	12″	0.220″	25	345	245	" "
	MP 42.38	1925	12″	0.220″	25	345	245	" "
	MP 42.47	1925	12″	0.220″	25	345	245	" "
	MP 42.91	1925	12″	0.220″	25	345	245	" "
	MP 42.95	1925	12″	0.220″	25	345	245	" "
	MP 42.99	1925	12″	0.220″	25	345	245	" "
	MP 43.14	1925	12″	0.220″	25	345	245	" "
	MP 43.19	1925	12″	0.220″	25	345	245	" "
	MP 43.81	1925	12″	0.220″	25	345	245	" "
	MP 43.97	1925	12″	0.220″	25	345	245	" "
	MP 44.18	1925	12″	0.220″	25	345	245	" "
	MP 44.22	1925	12″	0.220″	25	345	245	" "
	MP 44.51	1925	12″	0.220	25	345	245	" "
	MP 44.57	1925	12″	0.220″	25	345	245	" "
	MP 44.62	1925	12″	0.220″	25	345	245	" "

"The worst performers among the oxy-acetylene welded lines have been those constructed before 1930, some which have experienced damage at a relatively high rate of over one repair/km (1.61 repairs/mi). Oxy-acetylene welding for major transmission lines appears to have been discontinued by SoCalGas after 1931."

"In contrast to oxy-acetylene welded piping, pre-WWII pipelines with electric arc welds have fared much better when influenced by traveling ground waves Damage under these conditions accounts for only 2.7% of the total repairs, which is 30 times less than the traveling ground wave damage in oxy-acetylene welded lines. Prior to WWII, welding practices often involved the use of unshielded arc techniques, which exposed the molten weld directly to the atmosphere."

"Damage from permanent ground deformation associated with surface faulting, liquefaction-induced lateral spread, and landslides represents only 9.3% of the repairs. This relatively low portion is associated with the relatively small percentage of surface area influenced by ground failure during an earthquake. Damage from permanent ground deformation can nonetheless be severe, resulting in some of the most conspicuous damage during a seismic event."

"Post-WWII electric arc welded pipelines in good repair have never experienced a break or leak as a result of either traveling ground waves or permanent ground deformation during a southern California earthquake. The lack of damage to post-WWII electric arc welded pipelines does not mean they are immune to permanent ground deformation. On the contrary, there is substantial experience with modern pipeline failures in areas of severe landslides. The repair record shows that modern electric arc welded gas pipelines in good repair are the most resistant type of piping, vulnerable only to very large and abrupt ground displacement, and generally highly resistant to traveling ground wave effects and moderate amounts of permanent deformation."

Appendix I contains additional information regarding transmission pipeline system leaks.

2.1.2.4 Distribution Piping System Leaks/Failures

In the more than 50,000 miles of the steel portion of the distribution system, only 154 leaks were found. This amounts to about 3 per 1,000 miles of pipe. The details of these leaks are given in Table 2.4. Eighty leaks were in mains and 74 were in services. *"The most common failures that occurred in the distribution system included (1) service broke away from main or leaked at main connection, (2) leak at threads in pipe, flanges, etc., (3) leak in a fitting such as a leak clamp, transition fitting, etc., and (4) leak at welds."*[4]

"Seven failures of pre-1930's cast iron valves occurred...(and)..a small number of failures occurred on pre-1930's threaded and coupled pipe. (Cast iron valves are usually connected to this vintage pipe)."[4]

TABLE 2.4: STEEL DISTRIBUTION SYSTEM
EARTHQUAKE CAUSED LEAKS

FAILURE LOCATION	PACIFIC MAINS	PACIFIC SERVICES	NORTHERN MAINS	NORTHERN SERVICES	MOUNTAIN VIEW MAINS	MOUNTAIN VIEW SERVICES
Pipe Weld	5	0	9	8	0	0
Pipe Body	5	2	20	14	3	1
Flanged/ Screwed Connections	2	4	9	17	2	0
Valve	0	0	12	3	0	1
Fitting	1	4	7	7	1	1
Unknown	4	1	0	11	0	0
Total Failures	17	11	57	60	6	3

Total Mains	80
Total Services	74
Total	154

For the plastic piping portion of the distribution system, which comprises approximately 35,000 mi, only 27 leaks were found. This amounts to less than one leak per 1,000 miles of pipe. This leak rate is about 30% of that for the steel distribution system *"Half of them.*.(the 27 leaks).. *occurred at either socket fusions or at older style transition fittings or risers."*[4]

In addition to the above leaks which were directly caused by the earthquake "*...there were also 536 leaks....*(in the steel piping)*....classified as earthquake related. These leaks occurred in pipe or joints weakened by corrosion, material defects, construction defects, unknown, etc. with the earthquake accelerating the subsequent leakage/detection."* [4]

"There was no geographically observable pattern to the piping system failures. Failure was attributable to pipe condition."[4]

Additional information regarding the performance of the steel and plastic pipe is given in Appendices I and II.

2.1.2.5 Damage to Meter Set Assemblies (MSAs) and Customer Piping

There are approximately 4.8 million meter set assemblies (MSAs) in the entire system. Surveys conducted by SoCalGas showed that there were about 6,500 MSA leaks in the affected

3,400 miles of distribution piping. This represents about 5% of the total 123,000 restores required by the earthquake. Many of the MSA leaks were so small that the leak could only be found with sensitive equipment.

Approximately 40% of the leaks occurred in the stopcock, 14% in the insulated bushing, 11% in the meter swivel, and the remainder at other locations or from other causes. Note that "..*Under "normal" leak survey conditions,....*(the gas company).. *averages 1.5 MSA leaks per mile of pipe surveyed.*" Thus, for the 3,400 miles of concern, about 5,100 leaks would have been expected under normal operational conditions without the earthquake. These normal leaks accounted for about 80% of those found after the earthquake.

Of the 15,000 leaks in the customers piping beyond the MSA: *"..approximately 7,000 occurred at appliance connectors. Many are believed to be failures of semi-rigid aluminum or copper connectors which are no longer being installed."*[4]. Additional information regarding the performance of the MSAs, and the customers piping beyond the MSA is given in Appendices I, II, and III.

2.1.2.6 Customer Outages and Restores

The data on outages and restores given in Table 2.2 were for the period ending February 7, *i.e.,* three weeks after the earthquake. It can be seen that about 79% of the outages had been restored. Of the remaining 31,400 meters, service could not be restored to 9,100 customers because of structural property damage. For the remaining 22,300 customers, service was to be restored when the customers returned home and/or when the property was determined to be structurally sound for gas service.

Note that less than 13% of the restores were attributed to actual leaks or damage. The remaining restores were due to customer or emergency personnel closing the gas meter due to the disaster. The great majority of these closings were attributed to the customer. As noted in Reference [3] *"While the intent of this action* (shutting off a gas valve) *is immediate safety, it can result in a long delay before service is restored because gas company technicians must test each system before turning the valve back on."*

2.1.2.7 Overview of the Fire Problem

"Firefighters said that their biggest problem after the quake was battling the numerous gas-fueled fires that erupted after the temblor broke underground gas lines and residents were unable to turn off their gas lines because shut-off valves were either located underground or could be controlled only by a special key used by gas company employees." [7]

Battalion Chief R. Jioras is quoted as saying that "*from a hill, within 15 to 20 minutes you could see a bunch of fires that-if not started by broken natural gas lines-were certainly aided by them. It was by far the most difficult thing we had to deal with.*" [7]

"Within minutes of Monday's massive earthquake, the orange glow of fires ringed the pre-dawn sky. Throughout the day, more than 30 blazes-several of them major-were reported, most in the San Fernando Valley from Granada Hills to Santa Clarita." [8]

"At least one person suffered serious burns but no deaths were attributed to any of the blazes, fire officials said." [8]

"As of Monday evening, firefighters said at least 30-and perhaps as many as 50-blazes had been reported in the (San Fernando) *Valley. Fires continued into the night."* [8]

"Overwhelmed by thousands of calls and with their resources stretched thin, fire officials at Downtown headquarters were unable to determine the exact location of each fire. Los Angeles Fire Department spokesman Bob Collis said the earthquake had knocked out the department's computer system, preventing the officials from tracking the fires." [8]

"An (early report) estimated 150 gas distribution lines and individual service lines ruptured, contributing to fire in some cases. All these breaks were reportedly under control by noon. However, Thomas O'Rourke, a Cornell University expert on the effects of quakes on pipelines, said many more gas and water lines may have fractured than originally known, with further fires possible over the next few days." [9]

2.1.2.8 Structural Fires

As can be seen from Table 2.2, the most detailed data regarding the extent of the gas- related structural fires are given in Reference [4]. It is important to note, however, that although the other two references only provide broad ranges of the estimated numbers of fires, these ranges are clearly consistent with the values from Reference [4].

Table 2.2 shows that there were 51 structural fires that involved gas, with 23 of the structures completely destroyed and 28 partially damaged. However, some of these structures were duplexes or apartment complexes so that actually 84 separate residences were affected to some extent by fire and 51 residences were completely destroyed. SoCalGas' task force investigation of the 51 structure fires revealed that 39% involved water heaters and 55% involved water heaters *and* other gas appliances. The task force stated its belief that there were two factors present where damaged water heaters caused and/or were involved in fires:

1. An inadequate or missing water heater strapping mechanism and

2. Weak or flimsy water heater legs.

Reference [3] concurred that inadequately secured water heaters are likely to tip over during an earthquake so that water heaters appear to be a source of gas leaks. It went on to state, however, that *"...even though natural gas leaks may have played a role in a significant number of the 30 to*

50 reported fries, this number is very small when compared with the total number of buildings exposed to significant shaking during the earthquake. Since residents of this area are aware of the dangers of gas leaks following an earthquake, many fires may have been averted by individuals shutting off the gas to buildings or appliances." [3] Additional details regarding earthquake-related structural fires are given in Appendix IV.

2.1.2.9 Mobile Home Fires

Of the approximate 350,000 mobile homes in SoCalGas' service territory, 172 mobile homes in three parks were destroyed by gas-fed fires. Reference [4] notes that, in many cases, fire would start at one coach and then spread to several others. It gives as an example that in one large mobile home park, eight separate fires led to the destruction of 57 coaches. Reference [3] notes that "*..Observations made at.....*(one) *development...destroyed by fire indicate that the method of unit-to-unit fire spread was primarily through windows. Once a unit became completely involved in fire, the thermal radiation was sufficient to cause the breakage of windows in an adjacent unit or to ignite combustibles within the unit directly through the windows."*

Both References [3] and [4] noted that lack of water and/or low water pressure was a contributing factor to the fire spread. The fire department reported that the low water pressure in the area combined with multiple independent fires and limited resources hindered fire fighting operations. Fire spread was stopped only by physical separations such as roads and open areas or by fire fighting operations.

Reference [4] indicated that *"...the primary cause of the mobile home problem is the lack of seismic bracing. The coaches were knocked off their 30 inch high stands, damaging their gas pipes/MSA's."* Additional details regarding the effects of the earthquake on Mobile Homes are given in Appendix V

2.1.2.10 Street Fires

Three natural gas street fires occurred because of leaks in the pipeline system. The most highly publicized one occurred in the 11600 block of Balboa Boulevard in Granada Hills. According to SoCalGas [4] *"At this location the earthquake caused a water main to break at two locations and created two holes in Balboa Boulevard approximately 900 feet apart. The Gas Company's 22-inch transmission line* (Line 120) *and a 6-inch distribution main running alongside the water main also broke at these locations.* (Line 120 was built in 1930). *Two adjacent pipelines* (Lines 3000 and 3003) *constructed in the mid and late 1950s and joined by arc welding, however, were not damaged."*

"The gas leakage from the 22-inch and 6-inch gas lines (at the 11600 block of Balboa Blvd.) *resulted in an explosion and fire. No explosion or fire occurred at the other location 900 feet away where both gas lines were also broken. The explosion and fire involving the 22-inch transmission line burned five residences. This line was shut down and the resulting street fire involving the six-inch line persisted for many hours and got extensive media coverage."*[4]

The other two street fires involved 1920s vintage pipe which failed at their oxy-acetylene welds. Neither fire caused damage to any structure or other facility. One of these fires occurred in the 400 block of Lincoln Boulevard in Santa Monica (line 40) and the other occurred in Fillmore on line 1001 at Highway 126 at the eastern city limits. The Line 40 fire was apparently of very short duration and the Line 1001 fire lasted for about an hour.

2.1.2.11 Water Heaters

The role of water heaters as a potential source of structure fires was summarized earlier under Structural Fires (§2.1.2.8). Additional details are presented in Appendix VI.

2.1.2.12 Earthquake Valves

During the process of restoring service, some information was obtained regarding the performance of earthquake valves during the earthquake. The data showed that 841 restores on customers property were attributed to earthquake valve closing due to the earthquake. Of these, 162, or about 20%, were found with partial leakage or damage. Thirty-eight, or about 5%, were found malfunctioning, *i.e.*, not completely closed, or would not reset.

2.1.2.13 Emergency Response by SoCalGas

The herculean response task that faced SoCalGas is best described in its own report of the earthquake [10]. According to SoCalGas, the Northridge earthquake resulted in the "*largest natural gas emergency response ever mobilized by SoCalGas. For 14 days, the Company operated full-scale, around-the-clock, with employees working twelve-hour shifts or longer to successfully assist more than 151,000 customers in the aftermath of the quake. The Company's Emergency Operations Center in downtown Los Angeles and the command posts at the Mountain View, Pacific and Chatsworth Region Headquarters near the quake's epicenter operated continuously for the first ten days of the emergency. At the recovery effort's peak, a team of 2,940 employees worked for a concentrated period of five days in the most impacted areas. Tremendous support was provided by 460 loaned employees from four neighboring utilities: Pacific Gas & Electric, San Diego Gas & Electric, Southwest Gas, and the City of Long Beach's municipal gas department.*

Within one hour of the earthquake, the Company's Emergency Operations Center (EOC) was staffed and functioning at the headquarters facility in downtown Los Angeles, as was a command center at Mountain View Region headquarters, located in the Monterey Park 24-hour Message Center facility. Additional command centers were opened shortly thereafter at our region headquarters offices located in Chatsworth (Northern) and Torrance (Pacific) to direct operations in the most affected areas. Those centers operated continuously for the next ten days.

In addition to the workers in the field, the Company's Call Centers and other offices provided 24-hour, seven-day-a-week support responding to more than 400,000 telephone and in-person customer requests for over two weeks. In January as a whole, the Company responded to a record number 853,000 calls and answered 62% of the calls within 60 seconds or less. It should be noted *that these accomplishments were achieved even though 1,300 (or 14%) of our own employees live in the most heavily damaged area and many were personally affected.*

The Company relied heavily on the supplemental/restore team members from the Headquarters groups to assist the regional personnel with all field activities, In total, approximately 1,000 supplemental team members were contacted at home and requested to report to various region sites.

In addition to successfully identifying and repairing more than 300 initial pipeline breaks and leaks in the 24 to 48 hours immediately following the earthquake, the Company was faced with the unprecedented task of determining the extent of the damage to gas facilities at tens of thousands of structures in a vast, diverse geographic area within a 10- to 15-mile radius of the epicenter. A comprehensive, three-part effort was unleashed to, (1) do extensive leakage surveys of all pipelines, (2) "sweep" neighborhoods by sending workers literally from meter to meter, and finally, (3) follow up with an army of trained technicians to restore individual service. A majority of this massive work was completed by the end of Day #12 (January 28).

Throughout the two weeks following the earthquake, the Company utilized various communications such as mass news media, telephone recorded messages, door-to-door flyers and other means to most effectively meet the needs of customers. We went through three distinct communication phases during these two weeks: emergency response in the first 24 to 48 hours; public safety/service messages over the first week; and finally, information to reach all of our customers with service messages.

By the end of the second week of the intense recovery effort, employees were being systematically moved back to their regular work assignments. On January 26th, most loaned utility workers from other companies were released. Our own supplemental work force (staff management and non- field workers) who are trained for these types of emergencies were sent back to their regular assignments by January 28. On Monday, January 31, all employees were back at their regular work locations and assignments." [10]

2.1.2.14 Emergency Response of Other Organizations

Table 2.5 summarizes the heavy response burden faced by the LA fire department during the period 1/17-1/24/1994 and on 1/17/1994 alone.

It should be appreciated that an accurate account of the response by public safety agencies on the day of the earthquake is impossible. Many agencies lost power and in some situations, dispatching capabilities. Many units, in accordance with the standard operating procedures of their jurisdictions, were self-dispatched. In many cases, accounts of incidents, their types and their outcome are, at best, "sketchy".

TABLE 2.5: FIRE DEPARTMENT OPERATIONS/RESPONSES (TRACKING PERIOD 1/17/94-1/24/94)

AGENCIES REPORTING

BURBANK	GLENDALE	L. A. CITY	REDONDO BEACH
COVINA	HAWTHORNE	L. A, COUNTY	SAN GABRIEL
CULVER CITY	INGELWOOD	MANHATTAN BEACH	SANTA MONlCA
DOWNEY	LA VERNE	MONROVIA	VERNON
EL MONTE	LONG BEACH	MONTEBELLO	O.E.S.

TYPE OF CALL	TOTAL RESPONSES FOR TRACKING PERIOD
GAS/ODOR INVESTIGATION	8,380
FIRE	3,364
MISCELLANEOUS	3,118

	RESPONSES ON 1/17/94
GAS/ODOR INVESTIGATION	5,059
FIRE	1,559
MISCELLANEOUS	1,198

Information became more accurate with the activation of local Emergency Operation Centers (EOCs). The EOC became a clearing house for activity. One of its primary responsibilities was to act as an information collection point, where accurate information could be collected, sorted, and acted upon. Documentation of incidents and damage assessments were also compiled here.

Due to damage to the facilities that EOCs were located in, damage to roads making travel difficult, and damage to the homes of personnel who comprise the EOC staff, it took several hours to activate an EOC fully.

The California Fire Incident Reporting System (CFIRS) records incidents based on type, cause, etc. For the tracking period of 1/17/94 - 1/24/94 there is only one recorded incident where it was determined that the unintentional release of natural gas was the cause of the fire. In addition, fire investigators and company officers from several agencies stated that the release of natural gas accelerated the fires and enhanced the damage the fire caused. But they were reluctant to point to gas as starting the fire.

The release of gas also compounded rescue efforts by turning almost every building into a potential source of an explosion. The unstable conditions, the potential for after shocks, and the possibility of an explosive environment created numerous problems for first responders. Many company officers and responders stated that in all of the confusion, it was extremely difficult to detect the presence of gas prior to entering an occupancy.

2.2 HURRICANES

Unlike earthquakes, hurricanes are predictable at least over a limited period of time. Weather satellites are able to track the eye of a hurricane long before it reaches land and can give a fairly good idea of the area that should expect to receive the brunt of the hurricane impact and its approximate time of arrival. This gives the gas industry and other response agencies ample time to prepare for the impending emergency. Also, unlike earthquakes, hurricanes manifest most of their damage on above ground gas services and meter connections, with the exception of occasional damage to underground pipeline systems due to the uprooting of trees.

In this section, the two hurricanes that impacted the east coast of the United States are reviewed. Their effect on gas industry operations and the emergency planning and response of the affected gas companies are described.

All of the damage information depicted in this report was obtained from individual gas companies and news accounts. National Oceanic and Atmospheric Administration has published natural disaster survey reports, but these reports did not contain any information regarding specific damage to the gas industry.

Many of the gas companies helped their customers during these disasters by delaying billing and deferring payment. Some of the gas companies have also distributed ice and propane gas, to the public through response agencies like the Red Cross. Gas companies also provided loans and other assistance to their own employees who were affected by the disasters.

The gas companies, in coordination with the response agencies, prioritized the impacted areas on the basis of need. Restoration services were then provided to high priority areas such as hospitals and restaurants.

2.2.1 Hurricane Hugo [11,12]

A cluster of thunderstorms which had developed off the coast of Africa eventually grew into Hurricane Hugo. It became a tropical depression on September 10, 1989, about 125 miles (200 km) south of the Cape Verde Islands. By September 13, the storm had gained enough strength and organization to be classified as a hurricane. Its eye crossed the southwestern coastline of St. Croix in the early hours of September 18. The hurricane then passed over Puerto Rico and the Bahamas. Hurricane Hugo hit the South Carolina coast with sustained wind speeds of 150 mph (67 m/s). Hugo's eye passed over the city of Charleston at 12:30 a.m. on Friday, September 22 with a forward speed of 30 mph (13.4 m/s). The tidal surge was almost 20 feet (6 m) in some locations. Hurricane Hugo was classified as a Category 4 storm on the Saffir-Simpson Scale. This scale is used to assign a semiquantitative measure to the strength of hurricanes in accordance with the definitions provided in Table 2.6 [13,14].

TABLE 2.6: SAFFIR/SIMPSON SCALE OF HURRICANE INTENSITY

Storm Category	Storm Surge (feet)*	Mean Wind Speed (mph)*	Effects
1 Weak	4-5	74-95	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal road flooding and minor pier damage.
2 Moderate	6-8	96-110	Some roofing material, door, and window damage to buildings. Considerable damage to vegetation, mobile homes, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of center. Small craft in unprotected anchorages break moorings.
3 Strong	9-12	111-130	Some structural damage to small residences and utility buildings with a minor amount of curtain wall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain continuously lower than 5 feet ASL may be flooded inland 8 miles or more.
4 Very Strong	13-18	131-155	More extensive curtain wall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Major damage to lower floors of structures near the shore. Terrain continuously lower than 10 feet ASL may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.
5 Devastating	18-	156-	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Major damage to lower floors of all structures located less than 15 feet ASL and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5 to 10 miles of the shoreline may be required.

* Specific locations and distances normally refer to the center of the tropical cyclone. Tropical cyclones generally cover thousands of square miles and affect areas far from the center.

The rapid movement of Hugo greatly reduced the maximum rainfall potential. Along coastal sections of South Carolina, rainfall was limited to between 4 and 6 inches while inland rainfall was between 2 and 4 inches. Hurricane Hugo caused 49 directly-related deaths in the U.S. and in other Leeward Islands. Ninety percent of the buildings were damaged or destroyed in St. Croix. St. Croix was left without water, power and telephone service. The island was stripped bare of its vegetation and power poles were downed. On the US mainland, electrical power was lost in most areas as uprooted trees, splintered poles, broken branches or debris severed power lines. Roofs were peeled off many buildings and homes. The Ben-Sawyer swivel-bridge connecting Sullivan's Island to the mainland near Charleston was severely damaged. Charleston county police's radio tower was smashed. Two major power plants of South Carolina Electric & Gas Company were damaged and were unable to generate power in the days immediately after the storm.

2.2.1.1 Storm Management by South Carolina Electric and Gas Company [15,16]

South Carolina Electric & Gas Company (SCE&G) distributes natural gas to approximately 203,000 customers and electric power to 428,000 customers in South Carolina. Approximately 59,000 gas customers are in the Charleston area. The damage incurred by SCE&G due to the hurricane was estimated at $56,000,000. The electric system incurred most of the financial impact. The hurricane-caused damage to the gas distribution system was less than $500,000. After the storm had passed, 300,000 customers were without power in South Carolina and 600 residential customers were without gas in the metropolitan Charleston area.

SCE&G natural gas and electric emergency plans were implemented during Hurricane Hugo. On September 18, SCE&G activated its storm procedures. In preparation for the hurricane, SCE&G began tracking the storm. The crisis team members were identified and their responsibilities were clearly defined. The inventories of fleet fuel supplies, distribution materials and equipment like poles, transformers, cross arms, fuses and wires were checked and supplemented. Service trucks were restocked with supplies that would be needed if Hugo hit the area. Commitments for additional crews were secured from out-of-state utilities in ten states. Eventually, these crews grew to represent 48 different utility companies from 15 states.

Members of the SCE&G's crisis management team met with the emergency preparedness office in order to review public evacuation plans, identify Red Cross shelter locations, view storm surge simulation maps, collect topographical and gas system maps, and develop coordination plans with the emergency control center. SCE&G management met with all employees and informed them of the current location of the storm, its expected course and its potential damage to the SCE&G gas distribution system. Personal hurricane survival checklists were distributed to all personnel. Employees were told to prepare for evacuation and safe shelter of dependents. SCE&G reviewed the emergency plans and agreed on the following priorities: first, public and employee safety; second, public and private property; and third, acceptability and continuity of service.

The chain of command was reviewed to facilitate orderly information flow and to direct the coordination of support services. The potential effect on the gas system was evaluated for gas leaks and fires, flooding, overpressure, windstorm damage, underpressure, and system shut down. Emergency coordinators were assigned for: communications; manpower; provisions; public information; vehicles, security, air patrol; control center; and for public and employee assistance.

According to SCE&G's report [16], ".. *the emergency plans were reviewed for:*

Communications	*The existing radios were to be used with repeater mode and direct mode. Telephones were to be used for communicating and no-huddle game plans were developed.*
Manpower emergency response teams	*Emergency response teams, self-contained for at least 24 hours were setup and were located in safe shelters. Team leaders were appointed for the teams. To facilitate the restoration process in outlying areas, which might be inaccessible after the storm, the utility stockpiled the supplies and equipment like chain saws, rope, axes, fuel, tires, life jackets, flashlights etc. in various distribution sites.*
Manpower aftermath management teams	*The aftermath management teams obtained maps of the city, equipment and recruited clerical and secretarial assistance. Transportation was arranged.*
Manpower communications/ support services	*Employee spouses and retired employees were recruited for laundry and cooking services.*
Provisions	*Self-contained field kitchens, potable water, ice, and self-contained refrigeration trucks were obtained. Short and long term shelter and lodging were reserved. Cash and rolls of coins were kept ready.*
Facilities	*All the equipment was tied down at the SCE&G facilities. The propane-air plant and tank farm are secured. Windows were taped and doors were sandbagged. Portable toilets were obtained. The emergency standby generators were tested. In order to prevent flood and wind damage to supplies that was available in the warehouses, SCE&G moved the material to less vulnerable storehouses.*
Public Information	*Information about gas shut-offs was communicated to the public.*
Review potential system impact	*Sectionalization plans for shut in were identified. Regulators were vented and the system pressure was lowered or raised".*

Company officials debated the merits of shutting down the gas supply and purging the system. Although shutting down and purging, ensured complete safety during and after the hurricane, and would have allowed the employees to retreat until after the storm, some disadvantages were associated with this scheme:

- ➢ It would be difficult to locate leaks in the system.
- ➢ Restoring service to all affected customers would be expensive and time-consuming.
- ➢ Gas would not be available to anyone.
- ➢ Restaurants would not be able to provide meals for emergency personnel and residents.
- ➢ Water may enter into the distribution system.
- ➢ SCE&G would have had to shut down, purge, lock off and then turn the system back on needlessly if the storm missed the Charleston area.

As a result of these considerations, SCE&G decided not to shut the system down. A control center was set up to assure rapid and accurate information exchange. After the storm, limited radio communications were available. Telephone service was intact. Travel was limited by the downed power lines and trees on the roads. The emergency response crew cleared the roads, and assessed and reported the damage to the system. Many company vehicle tires were punctured due to roofing nails and other debris. The storm destroyed and damaged many company vehicles and the fleet maintenance facility. Fuel tanker trucks were brought for direct fueling of the vehicles. A massive tire changing operation was also begun.

The inaccessible areas of SCE&G distribution system were patrolled by air. Public notices about appliance controls and venting, inspection, repair, and replacement were released. An underground utility locating service was provided to all contractors, customers, and other utility companies who were excavating. Valve maintenance and leak surveys were delayed due to the large amount of debris along public rights-of-way and road clearing activities. All company and contractor vehicles and personnel were provided identification badges. Regulators in flooded areas were tested for operating and lock-up pressures. All pipelines attached to bridges and all above ground structures were checked. The control center coordinated road clearing and temporary road construction work and collected information on leaks. Security was increased at all of the distribution centers and company facilities due to the heavy looting that followed the hurricane.

2.2.1.2 Damage to SCE&G's Gas Piping System

By the end of 1989, the numbers of Hugo-related gas work orders received were:

Leak orders	1,827
Broken Services	384
Broken Mains	19
Miscellaneous	4,600

About 750 gas leaks were detected. Four-hundred gas meters had to be locked, first for safety reasons and then for repair. Lines that were infected with sand and salt water were purged. Some gas leaks occurred due to the disconnection of service lines, when houses and mobile homes were dislodged off their foundations. The most severe damage to the natural gas distribution system occurred on a coastal barrier island in the town of Folly Beach.

The severe windstorms and flooding resulted in severing or uprooting of gas mains and services, and the destruction of customers fuel lines, venting systems, meters and regulating stations. There were no gas fires. An increase in the non-registering residential meters was observed. Some gas lines were damaged by customers excavating tree stumps from their property. In the aftermath of the hurricane, there was a dramatic increase in the requests for locating underground gas lines. Part of the reason for this increase was the acceleration of the telephone utilities' plans for underground systems.

2.2.2 Hurricane Andrew [17]

A tropical disturbance, which was spawned in the central equatorial Atlantic Ocean on August 16, 1992, grew into Hurricane Andrew. On August 24, it hit south Florida as a category 4 storm (see Table 2.6) at 5 am EDT with a sustained wind speed of 145 mph (64.5 m/s) and gusts of over 175 mph (78 m/s). Andrew traversed south Florida and entered the Gulf of Mexico. As a category 3 storm, Andrew made its landfall in Louisiana at 4:30 am EDT on August 26. In Louisiana, the sustained winds were estimated at 120 mph (53.5 m/s) with higher gusts. Andrew was an intense, compact, fast-moving and relatively dry storm, which limited the duration and amount of rainfall. The storm surge was more than 14 feet, with storm tides reaching nearly 17 feet over a limited area. In Louisiana, 14 confirmed hurricane-spawned tornadoes were reported.

The high winds and storm surge effects of the storm were limited to a relatively small area of coastal floodplain. The extremely strong pressure gradients and resulting intense winds in and near the eye wall were the prime cause of structural damage during Andrew. Some 126,000 houses were destroyed or damaged and 9,000 mobile homes were destroyed in Florida. Wood frame houses and mobile home parks were completely destroyed. The loose enforcement of South Florida's building codes apparently contributed to the destruction. The municipal electric power grids in Homestead and Florida City were destroyed.

In Louisiana, about 3,300 single family, multifamily and mobile homes were destroyed, and over 18,000 units were damaged. Total damage was estimated at about $25 billion in south Florida and more than $1 billion in Louisiana. Of the 3,800 natural gas drilling platforms, 13 were toppled over while 100 more were damaged. One of the tornadoes spawned by Hurricane Andrew damaged a pipeline at an offshore natural gas rig, and caught fire. The fire was left to burn itself out.

In its report [17], the Building Performance Assessment Team of Federal Emergency Management Agency (FEMA) examined *"..the performance of residential buildings in the storm's path. The assessment team assessed the primary structural systems of buildings, i.e., systems that* *support the building against all lateral and vertical loads experienced during a hurricane. The masonry buildings and wood-frame modular buildings survived relatively intact. The performance of the exterior architectural systems, such as roofing, windows and doors was analyzed. The analysis included the effects of debris and the quality of construction workmanship. Failure of manufactured homes and other metal-clad buildings generated significant debris. Numerous accessory structures, such as light metal porch and pool enclosures, carports, and sheds, were destroyed by the wind and further added to the debris. Much of the damage to residential structures also resulted from inadequate design, substandard workmanship, and/or misapplication of various building materials. Inadequate design for load transfer was found to be a major cause of the observed structural failures of buildings. Inadequate county review of construction permit documents, county organizational deficiencies such as shortage of inspectors and inspection supervisors, and the inadequate training of the inspectors and supervisors are factors that may have contributed to the poor-quality construction observed."*

2.2.2.1 Emergency Response of City Gas Company of Florida [18]

City Gas Company of Florida provides natural gas to about 200,000 customers in the South Florida, including Miami. The company's distribution lines are made of plastic and the service lines are made of steel. During Hurricane Andrew, some gas lines and gas meters were broken. A natural gas odorant station was destroyed by the storm causing a loss of 18,000,000 scf of gas. According to City Gas, many customers closed their gas valves needlessly, because the media suggested that they do. Other electric companies excavating to install the downed electric poles without locating the underground natural gas pipes caused some breaches to the gas system. Some damage was also caused by reconstruction after the storm. By Friday, City Gas Company had received 1,466 calls from customers about leaks and restoration. By the 9th week after the hurricane, the calls were reduced to the pre-storm daily average number of calls. There were no gas related fires. Gas appliances were damaged by floods. Utility employees checked all gas fired appliances before resuming gas service to these customers. Some gas leaks occurred due to the disconnection of service lines, when houses and mobile homes were dislocated from their foundations.

City Gas Company of Florida has an emergency plan for natural disasters that was implemented during Hurricane Andrew. City Gas was continuously monitoring the storm. A control center was set up to assure rapid and accurate information exchange. The control center coordinated the flow of information. The potential effect of the hurricane on the gas system was evaluated. Sectionalization plans for shut downs were identified. Regulators were vented. City Gas Company decided to use telephones and radios for communication. Information about gas shut-offs was communicated to the public. City Gas Company decided to keep the gas supply on so as to minimize water entry into the distribution system, and eliminate the need to shut down, purge and turn the system back on. Members of the control center met with the local emergency response personnel to view storm surge simulation maps, secure topographical and gas system maps and review public evacuation plans. During the storm, the utility was continuously monitoring the gas pipeline system.

The control center coordinated the mobilization of the radio despatch crews. Roads were impassable mostly because of fallen trees and power lines. The emergency response teams crew assessed and reported the damage to the system. An underground utility locating service was provided to all contractors, customers, and other utility companies who were excavating. Regulators in flooded areas were tested for operating and lock-up pressures. All pipelines were checked for leaks. The heavy looting that ensued limited the utility's response work to daytime only.

2.2.2.2 Emergency Planning of Other Gas Companies

Several small gas companies provide natural and LP gas service to small communities along the eastern coast of Florida. Indiantown Gas Co. (IGC), for example, serves 450 LPG customers, 550 natural gas residential customers and one large industrial gas consumer in Indiantown, FL. Although not affected by either hurricane, IGC takes special precautions before the arrival of a hurricane. It tracks the hurricane movement continuously on a TV monitor which receives weather information via satellite from a private national network called Data Transmission Network (Omaha, Nebraska). IGC boards up the windows of its solid concrete building with pre-prepared wood planks. It fills its large horizontal propane cylindrical storage tanks so that they cannot be lifted by the wind. Small cylinders which are normally stored outdoors are removed to interior storage. Wind has been known to topple and roll these cylinders on the ground.

Under a voluntary safety program developed by the National Propane Gas Association and GAMA, all LPG users will have been visited during 1995 and 1996 by IGC personnel and personally instructed in LPG and appliance safety and advised to shut off their appliances before the arrival of a hurricane or when there are tornado warnings. IGC plans to continue this program for its natural gas users.

South Florida Natural Gas Company (SFNG) serves the area of New Smyrna Beach, Sugar Mill and Edgewater, FL. It has about 4,000 customers and distributes natural gas over a network of some 170 miles of mains. In addition, it provides gas to three electric power generation plants.

SFNG, which has developed a comprehensive Hurricane Manual, derives its information about approaching hurricanes from the public media. Four days before expected landfall, SFNG begins a series of meetings with its employees and initiates a formal daily program to update information and build up the company supplies and resources. As the hurricane approaches, it boards up its windows and reviews its hurricane manual and individual assignments with all of its employees. The public is reminded through local television and radio stations to shut gas flow at the meter. Arrangements are made with local car mechanic shops to stay open in order to fix tire punctures in company vehicles due to roofing nails and debris. During the hurricane, communications are maintained with the City/County coordinators and the local police and fire departments. The telephone system has been found to be more reliable than portable radio systems during these emergencies because of the toppling of radio towers. After the hurricane, the crew is dispatched to repair reported gas leaks, check for any additional leaks, relight pilots and locate underground gas lines for the other utilities.

2.3 FLOODS

2.3.1 The "Great" Flood of 1993 [19]

Record and near-record precipitation during the spring of 1993 on soil saturated from previous seasonal precipitation, resulted in flooding along many of the major river systems and their tributaries in the Upper Midwest. Flood records were broken at 44 forecast points on the Mississippi river system, at 49 forecast points on the Missouri River system, and at 2 forecast points on the Red River of the North System. The historic flood of record on the Mississippi at St. Louis was established on April 28, 1973, at 43.2 feet; and reestablished on August 1, 1993 with a record flood stage of 49.6 feet.

Spring flooding began in March due to a previous wet fall, normal to above-normal snow accumulation and rapid spring snow melting accompanied by a heavy spring rainfall. Some parts of South Dakota went above flood stage in May and remained flooded through mid-June. Throughout the summer, large areas along the Missouri and Mississippi were flooded. Major flooding continued throughout the middle of September in many areas along the Mississippi. The flood of 1993 can be considered to be the result of the cumulative effect of an unusual number of substantial flash flood events combined with certain adverse climatological conditions including previous heavy rains. Flash flooding is a localized rapid rise in water levels in smaller streams or in low spots.

The Midwest "Great" Flood of 1993 inundated more than 20 million acres of land in nine states. At least 75 towns were completely submerged under flood waters. About 50,000 homes with associated properties were damaged or destroyed. Barge, rail and truck traffic was completely halted in some areas. Several miles of railroad track were flooded, and the rail beds were eroded. Twelve commercial airports were closed.

2.3.1.1 Flood Management by Iowa-Illinois Gas and Electric Company [20]

Iowa-Illinois Gas and Electric Company (IIG&E), Bettendorf, Iowa, provides natural gas to 179,611 customers in Iowa and 64,451 customers in Illinois. Of these, 223,312 are residential customers and 20,750 are industrial customers. IIG&E has an emergency response plan for natural disasters.

According to company records, the two-highest Mississippi river floods recorded in the Quad-Cities occurred in 1965 and 1993. The Quad-Cities consist of Bettendorf, Moline, Rock Island and Davenport. The flood stage in Quad-Cities is 15 feet and the 100-year flood level is 23 feet. The water level reached a height of 22.63 feet during the 1993 floods and a height of 22.4 feet during the 1965 floods. Dikes and flood walls are built along the river in the Quad-Cities area.

The Mississippi river water level is tracked by the U.S. Army Corps of Engineers. IIG&E uses the U. S. Geological survey maps provided by the U. S. Army Corps of Engineers to monitor the flooding levels and predictions on a continuous basis. IIG&E identifies the risk areas, emergency valve isolation systems, and the roads that might be inaccessible during the flood. The company also identifies the backup separation areas in case additional flooding occurs due to dike failure. In preparation for a flood, the vents and drips are raised above the expected flood level.

An in-house Incident Command System is set up by the company during floods. Available in the Incident Command room are the maps of the surrounding area with pipeline and valve locations marked. Also available are the U.S. Geological survey maps showing the water level and the terrain of the area. Teams of IIG&E personnel survey the area for leaks in pipes or for floating pipes. Boats are used as the mode of transportation. Special attention is paid to pipes that cross rivers or creeks, and those in changing grade areas. The survey personnel are in contact with the Incident Command room by means of radios and cellular phones. All actions are monitored and recorded. A helicopter is also used for surveying the water level. In case of a leak, that section of the pipe system is isolated and shut-off.

Gas supply is cut only if residents request it, if the company determines that keeping the gas could be hazardous, or if local city/county or disaster officials request that the services be disconnected. Arrangements are also made with other utility companies in the area and gas companies in other areas in case of shortage of work force.

The Incident Command Room at the IIG&E also receives phone calls from the customers who want their gas supply to be turned off and direct the survey teams to these locations. The company ensures that all employees who might get into contact with the flood water are given tetanus and booster tetanus vaccinations. During the flood, information about emergency shut-offs was communicated to the public through the news media.

After the flood water had receded, personnel from the gas, electric and appliance divisions of the company visit each of the affected customers and check their meters, pipes and connections. The city requires that all customers who were flooded must have their appliances checked and certified by the city, before gas and electric supplies are resumed to those customers. Gas personnel check for any shift in the gas pipes and for leaks using flame ionization detectors. IIG&E also hires a diving company to conduct an underwater survey of the cover above high pressure pipelines in the river. The pipes in the river are anchored in accordance with Department of Transportation regulations 49 CFR 192.327 (e) and 192.161. The company has started a pipeline replacement program in which all of its cast iron pipe will be replaced by plastic pipe within ten years. The company is presently in its fourth year of the ten-year project.

Less than 500 customers along the river were affected by the floods. Most of the damage was related to gas-appliances which were flooded. The customers had to get their appliances checked and certified by the city before gas supply was resumed. Some meters and valves which were flooded had to be replaced. Water leaked and filled some low pressure mains, stopping the gas flow. However, this did not pose any danger. These pipelines were isolated, cleaned and put back in service.

During the 1993 floods, the banks of the Mississippi river were so eroded at Cedar Rapids that a gas pipeline was exposed, but no damage was incurred. There are some mobile home parks in the Quad-Cities area, but no major incidents involving mobile homes occurred. In the last ten to fifteen years, only once did the flexible connection to a mobile home get disconnected during floods. There are no excess flow valves on the flexible connections from the gas meters to the mobile homes.

2.3.1.2 Flood Management by Laclede Gas Company [21, 22]

Laclede Gas Company distributes natural gas to about 600,000 customers in the St. Louis Metropolitan and eastern Missouri areas. During the height of the flood, gas service was interrupted for about 10,000 customers.

During the "Great" Flood of 1993, Laclede continuously monitored the flooding levels and predictions. The pipelines were patrolled by air. The gas was shut off to customers before flooding actually occurred, so that the pressure would be maintained in the system, thus preventing water and silt seepage into the pipeline. Service lines to buildings were shut off. Gas supply to mobile home parks was shut off and the lines were disconnected, so that leaks could be prevented if mobile homes floated in flood waters. Valves were identified and staked ahead of time so that they were accessible for isolating sections of the distribution system even with a small amount of water level on the ground. Emergency shut down plans of various portions of the system were developed.

Laclede had a senior operations command post on a 24-hour basis staffed by engineers, records personnel, management personnel and operating staff. The command post was maintained throughout the worst part of the flood. Field personnel were scheduled so that coverage could be provided on a 24 hours per day 7 days per week basis. The supervisory and management staff were also scheduled to work to assure continuous coverage. Field command posts were setup with a dedicated supervisor responsible for coordinating all communications. With this formalized mechanism through which field communications were filtered, it became much simpler to ascertain whether or not particular information was accurate. A detailed log of all significant information reported and actions taken was maintained. This log facilitated the transfer of responsibility between shifts. A daily liaison with all relevant emergency personnel and agencies was maintained. The activities of all utility work forces were coordinated. Laclede issued a statement through the news media relative to emergency shutoffs, billing, and gas service restoration.

After the flood, the integrity of the distribution system was checked. Flame ionization detectors were used to locate leaks. Pipeline depth of cover surveys, pipeline marker surveys and engineering evaluations of washed out and eroded areas were carried out. Water and mud were removed from the distribution systems that were flooded. The condition of structures was ascertained.

Failure of several levees and pumps used to drain water from the dry side of levees caused flooding behind levees in the River Des Peres area in Southern St. Louis. Channelization of the Mississippi through the construction of levees caused the mean height of the flood to be much higher than planned and many of the levees were not designed for this. A 16-inch transmission pipeline was exposed due to the failure of a levee in the Labadie Bottoms area. Some trees were lying across the exposed pipe. About 65,000 cubic yards of material was removed by the river from under the pipe. This concrete covered pipe floated due to its slight buoyancy. Because it was expected that this pipe would lose its support and collapse when the water receded, scrap bag supports were wedged underneath the pipe. The support bags were installed by divers. A pipeline belonging to Explorer Pipeline Products Line Company was also exposed.

Gas is served to riverfront boats in the St. Louis area with flexible piping connected to special meter sets. Some boats broke loose and suffered major damage.

Several take points of the main pipeline which supplies gas were flooded. One of the stations was under water for well over a month. There was substantial damage to the equipment. Control valves in some stations were flooded, but Laclede was able to keep these stations in service by keeping all control equipment above water.

2.3.2 San Jacinto River Floods, 1994 [23,24]

On October 16, 1994, the San Jacinto river, swollen by more than 30 inches of rain, began to flood. The San Jacinto river is located in the southeastern part of Texas. It flows into the Houston Ship Channel, which flows into Galveston Bay, and eventually the Gulf of Mexico. About 12,000 people were forced to evacuate their homes due to flooding. Mobile homes, cars and other large objects were washed into the river by the flood.

A 20-inch crude line belonging to Texaco, a 12-inch natural gas line belonging to Valero Natural Gas Company, and a 40-inch gasoline and a 36-inch diesel pipelines belonging to Colonial Pipeline were exposed when flood waters scoured out a portion of the river bank. All of these unsupported pipelines seemed to have broken at about the same time. The vapors from the liquid spill were ignited by an electric generator at a nearby mobile home. The flames were carried downstream by the floating burning liquids. It does not appear that the gas was ignited.

The pressure in this natural gas pipeline was more than 400 psig. The pipeline had block valves on both sides of the river which were promptly closed. Valero Natural Gas Company has since replaced 750 feet in this section of the pipe with a concrete, lead-weighted pipe to prevent it from rising during future flooding events. Another gas pipeline was braced when it was found that it was sagging. Several other pipelines were undermined but did not break.

3. CURRENT STANDARDS AND PRACTICES

3.1 EARTHQUAKE PROTECTION

Past and present efforts to reduce earthquake effects can be divided into two general categories:

1. Defining the threat by characterizing the properties of earthquakes and the response of the terrain as determined by location both, with regard to geology and distance relative to epicenter, and the properties of the ground;

2. Mitigating the threat, preferably by avoiding areas susceptible to ground displacement, or, when necessary, engineering the structure to accommodate the anticipated threats of ground displacement around buried pipe lines; and of surface waves for above-ground parts of the gas-delivery system.

Reference [25] describes some efforts to characterize earthquakes by measuring transient peak accelerations, velocities, displacements, and the frequency spectrum of the waves during episodes of strong shaking.

Ground failure modes include liquefaction, differential settlement, lurching, thrusting, displacement, landslides, and avalanches. Arrays of recording accelerometers and geological borings are supplying some characteristics of earthquakes and the associated ground responses as functions of soil structure, but many more data are needed to render forecasts of threatening earthquakes of acceptable reliability. Reference [26] notes that traveling ground waves from an earthquake generally do not damage steel pipe assembled with sound welds. Most damage of such pipes results from large permanent ground deformations caused by surface faulting, soil liquefaction, and land slides.

Natural gas piping systems here refer to the underground transmission and distribution systems of the gas companies as well as the MSAs and piping on the customer's side of the MSA. Each of the current standards and practices is referenced.

3.1.1 Special Pipeline Replacement Programs

3.1.1.1 Previous Activities

Past activities fall into two categories:

1. Replacing the weakest elements in the system. Certain families of piping materials, e.g., copper and cast iron, have been replaced (i.e., totally removed from the SoCalGas system [4]). Significant progress has been made in replacing pre-World War II acetylene welded, high-pressure, steel pipelines.

2. Changing the design safety factor as the location class changed [27], in particular, as new buildings for human occupation encroached upon the pipeline right of way.

Weak elements include cast iron pipe, some early types of plastic pipe and fittings, corroded steel pipe, and steel pipe with weak welds. For example, PG&E replaced the entire distribution system in the San Francisco Marina District after the Loma Prieta earthquake. Design factors in new construction have usually been upgraded to meet the safety factor requirements by adjusting the strength of the pipe through changes in either wall material or wall thickness [27]. Existing lines have been made to conform to more stringent safety factors by simply reducing the operating gas pressure.

3.1.1.2 Current Practices

Sections of line are being replaced in active fault crossings, liquefaction zones, and landslide areas, as well as in locations where high densities of people frequently congregate and live. [4] For gas companies in the active earthquake areas of both northern and southern California, replacing the weakest elements in the system is a continuing process. In northern California, for example, Palo Alto Gas Utilities is in the midst of a five-year replacement program. Having no high-pressure transmission lines, Palo Alto's goal is to replace all steel and outmoded plastic pipe with the newer, improved plastic materials. Also in northern California, PG&E uses "smart pigs" to locate corrosion, weak welds, and any mechanical damage in transmission lines. Any observed weaknesses are given high priority in PG&E's program of replacement and maintenance.

The California gas companies are also improving their flexibility for emergency response by adding valves to the system to attain an isolation grid of smaller cells. This would be expected to reduce the number of services disrupted due to the isolation of a leak to permit repair of the system.

Increasingly, the gas companies are monitoring early warning of problems (e.g., leaks) in their systems. Gas pressures and flow rates are computer-monitored at numerous locations in the distribution system. Enhanced forms of computer software are improving gas companies' capability for diagnosing the failure and determining its location, thereby expediting response.

Some gas companies are monitoring stress and strain in pipelines at sensitive locations. For example, SoCalGas has installed strain gages on transmission lines in seismically active areas to measure stress buildup in the pipeline during seismic episodes.

An example of active post earthquake mitigation entails releasing stress in pipelines. Two methods of stress relief have been used:

1. Re-alignment where ground displacement has bent the pipe out of alignment;

2. Removing a section to relieve compressive stress along the axis of the pipe caused by soil compression.

There is also a program in seismic design of pipelines tailored to anticipated problems at active sites. According to Reference [25], several approaches are used for estimating the maximum earthquake threat at a given location:

1. The length of the causative fault is taken as a proportionate measure of the threat. A common method, used in areas of active faulting, is to forecast the maximum earthquake magnitude from the length of the causative fault. It is said to be mechanistically impossible for a large earthquake to be generated on a fault of small length. One can see in the world-wide data of historical earthquakes a rough correlation between fault rupture length and earthquake magnitude; and, based on historical observations, it is often assumed that half the fault length can rupture in a single slip event. [25]

2. In the second approach, attention is paid to measurements of the amount of displacement in exposed faulting associated with prehistoric earthquakes. As in the case of fault length, a rough correlation exists between earthquake magnitude and displacement.

3. In the absence of active faults, the historical record of earthquakes in an area may provide the only indication of the threat.

4. Finally, it has been postulated by some seismologists that micro-earthquakes can be extrapolated to macro-earthquakes. Seismographic data for small earthquakes or man-made explosions may provide some clues as to the nature and frequency of large events; but, as in the other methods, these estimates are not very quantitative.

Having defined the reasonable worst-case threat scenarios, the gas companies apply engineering techniques for mitigating seismic threats appropriate to such threats. For example, gas pipelines can be decoupled from the Earth's motions. This approach is commonly used on large diameter transmission lines in locations where they cross a fault. Reference [28] describes the procedure for estimating strain produced in the pipe, and the design of the trench and its backfill to allow for the contingency earthquake. Particular features are the length of the special trench on each side of the fault, maximum depth of cover over the pipe, specifications of granular cohesionless backfill material, and maximum width of padding on each side of the pipe, i.e., how wide the trench should be. Sometimes the sides of the trench are sloped outward (i.e., flared) to lessen constraint on the pipe if earth displacement should occur. Another approach is to increase pipe flexibility with movable joints [29].

3.1.2 Installation of Plastic Pipe

Since 1969, SoCalGas has installed plastic pipe where possible because it is believed to be less subject to earthquake damage. A similar practice has been followed in northern California.

Today, about 41% of SoCalGas' distribution system consists of plastic pipe. The company states that *"..Initial reports of the response of the plastic pipe to seismic activity in the Northridge earthquake are quite favorable with over half of the 27 plastic piping failures occurring at either socket fusions or at older style transition fittings or risers."*[4]

It was previously noted that Palo Alto Utilities, which has no high-pressure transmission lines, plans to have an all-plastic system within five years. Pacific Gas & Electric is converting its low-pressure (less than 60 psig) distribution lines to polyethylene (PE) plastic pipe. This conversion process, which started in 1985, is designed to replace all cast iron pipe. Plastic lines are tested with air at close to 100 psig.

3.1.3 Meter Set Assembly and Customer Piping

A typical MSA is primarily supported by a riser from the earth-buried service line, and has a rigid connection to the customer's piping system. During an earthquake, relative movement of the MSA with respect to either the ground or the building can subject the pipe, its joints, bends, and couplings to forces exceeding the onset of failure.

A large proportion of gas appliances are connected to the internal gas supply line with rigid or semirigid connectors. These are a common point of failure when the appliance is displaced or overturned.

3.1.4 Structural Fires and Water Heaters

As noted in Chapter 2 of this report, gas-caused and gas-fueled structural fires are frequently associated with water heater displacement. Water heater stabilizing systems, such as strapping to the nearest wall, have received considerable attention by the gas companies in seismically active areas.

In southern California, SoCalGas reports that *"A simpler water heater strapping design was investigated with the intent of having a cheaper price for SoCalGas strapping program, thereby increasing the number of water heaters strapped by the Company. Although simpler designs are possible, the cost would not be reduced enough because of the labor intensive nature of installing strapping devices."*[4]

3.1.5 Mobile Homes

Current gas piping practices are not significantly different from those used for other residences. Flexible hookups are occasionally provided at the supply point, but the connections to the building are often too short-coupled and rigid to provide for earthquake motions. The special vulnerability of mobile homes is due to the lack of seismically resistant foundations. The desirable increase in separation between supply riser and building, to absorb differential movement, is hard to regulate because, unlike conventional residences that are constructed in their permanent location prior to installing their gas supply, mobile homes are commonly located (or relocated) where a gas supply system already exists.

Mobile home parks are supplied with natural gas by two different modes of service:

1. Individually metered (IM) hookups, which are separately serviced by the local gas company; and

2. Master-metered (MM) systems, in which individual hookups are provided and serviced by private owners of the park.

In IM parks, each mobile home is supplied gas directly by the gas company, which is also responsible for the supply distribution piping system within the park. Each individual MSA is located at each mobile home unit, and the meter changing tee, located at the MSA, is considered the responsibility transition point from the gas company to the customer. In MM parks, the gas company supplies gas at one or more locations, depending on the size of the park. The park owner then has responsibility for the installation and maintenance of the system, including piping, meters, regulators, leakage, and compliance issues. See Appendix V for additional information.

3.1.6 Earthquake Valves

Currently, the gas companies are opposed to mandating the use of automatic shutoffs because of the time and labor investment that such devices, if widely used and unregulated, would impose on the restoration of service following even a modest temblor. They do, however, support the right of home owners to install such a device if they so wish. In fact, SoCalGas is reported to be planning to offer a program to install such devices. See § 4.1.6.2 for details.

3.1.7 Isolation Areas

Failures in the gas distribution system entail shutting down whole sections of the network, thereby interrupting service to a large number of customers whose properties may not be endangered. To minimize unnecessary interruption of service, gas companies have been subdividing their networks into a finer grid.

Implementation of this goal is illustrated by a quote from the SoCalGas' report on the Northridge earthquake that: *"In conjunction with the CPUC Safety Branch, in 1986, a program was begun to install 4,500 valves to insure the Company's ability to rapidly shut off the flow of gas during emergencies."*[10]

3.1.8 Facility Hardening

Southern California Gas Company reports that *"Since 1989, the Company has implemented a program to improve structural integrity and interior support systems at its critical operating buildings. This has included building its two newest Region headquarters buildings and one customer call center to 'essential structure' criteria (uses a design factor of 1.25 of the current building code requirement), as well as retrofitting four other buildings to those criteria. In some* *buildings, internal bracing of ceiling and HVAC systems has also been undertaken. The result of these efforts was demonstrated in* (how well) *the...Chatsworth region headquarters building withstood the* (Northridge) *earthquake."* [10]

3.2 HURRICANES AND FLOODS

3.2.1 Federal Standards Relating to Pipeline Protection against Natural Hazards

The Pipeline Safety Regulations, 49 CFR 192 issued by the Office of Pipeline Safety and the Research and Special Programs Administration, U.S. Department of Transportation [30], prescribe minimum safety requirements for pipeline facilities and the transportation of natural gas. Relevant sections which deal with the protection of pipelines against natural disasters are reproduced below:

§192.161: Supports and Anchors

Although not specifically dealing with flooding, this paragraph addresses the need for supports and anchors to resist longitudinal forces and to damp out excessive vibration.

§192.317: Protection from Hazards

(a) *Each transmission line or main must be protected from washouts, floods, unstable soil, landslides, or other hazards that may cause the pipeline to move or to sustain abnormal loads. In addition, offshore pipelines must be protected from damage by mud slides, water currents, hurricanes, ship anchors, and fishing operations.*

(b) *Each aboveground transmission line or main, not located offshore or in inland navigable water areas, must be protected from accidental damage by vehicular traffic or other similar causes, either by being placed at a safe distance from the traffic or by installing barricades.*

(c) *Pipelines, including pipe risers, on each platform located offshore or in inland navigable waters must be protected from accidental damage by vessels.*

§192.319: Installation of Pipe in a Ditch

(c) *All offshore pipe in water at least 12 feet deep but not more than 200 feet deep, as measured from the mean low tide, must be installed so that the top of the pipe is below the natural bottom unless the pipe is supported by stanchions, held in place by anchors or heavy concrete coating, or protected by an equivalent means.*

§192.327: Cover for transmission pipelines and mains

(e) *All pipe which is installed in a navigable river, stream, or harbor must have a minimum cover of 48 inches in soil or 24 inches in consolidated rock, and all pipe installed in any offshore location under water less than 12 feet deep, as measured*

from mean low tide, must have a minimum cover of 36 inches in soil or 18 inches in consolidated rock, between the top of the pipe and the natural bottom. However, less than the minimum cover is permitted in accordance with paragraph (c) of this section.

§192.355: Customer Meters and Regulators: Protection from Damage

(b) ...the service regulator vents and relief vents must..... (3) Be protected from damage caused by submergence in areas where flooding may occur.

§192.402: Operation and maintenance

(e) (2) Prompt and effective response to a notice of each type emergency, including fire or explosion occurring near or directly involving a pipeline facility, accidental release of hazardous liquid from a pipeline facility, operational failure causing a hazardous condition, and natural disaster affecting pipeline facilities.

§192.615: Emergency Plans

(a) Each operator shall establish written procedures to minimize the hazard resulting from a gas pipeline emergency. At a minimum, the procedures must provide for the following:

(1) Receiving, identifying, and classifying notices of events which require immediate response by the operator.

(2) Establishing and maintaining adequate means of communication with appropriate fire, police, and other public officials.

(3) Prompt and effective response to a notice of each type of emergency, including the following:

(I) Gas detected inside or near a building.

(ii) Fire located near or directly involving a pipeline facility.

(iii) Explosion occurring near or directly involving a pipeline facility.

(iv) Natural disaster.

(4) The availability of personnel, equipment, tools, and materials, as needed at the scene of an emergency.

(5) Actions directed toward protecting people first and then property.

(6) Emergency shutdown and pressure reduction in any section of the operator's pipeline system necessary to minimize hazards to life or property.

(7) Making safe any actual or potential hazard to life or property.

(8) Notifying appropriate fire, police, and other public officials of gas pipeline emergencies and coordinating with them both planned responses and actual responses during an emergency.

(9) Safely restoring any service outage.

(10) *Beginning action under §192.617, if applicable, as soon after the end of the emergency as possible.*

(b) *Each operator shall:*

(1) *Furnish its supervisors who are responsible for emergency action a copy of that portion of the latest edition of the emergency procedures established under paragraph (a) of this section as necessary for compliance with those procedures.*

(2) *Train the appropriate operating personnel to assure that they are knowledgeable of the emergency procedures and verify that the training is effective.*

(3) *Review employee activities to determine whether the procedures were effectively followed in each emergency.*

(c) *Each operator shall establish and maintain liaison with appropriate fire, police, and other public officials to:*

(1) *Learn the responsibility and resources of each government organization that may respond to a gas pipeline emergency;*

(2) *Acquaint the officials with the operator's ability in responding to a gas pipeline emergency;*

(3) *Identify the types of gas pipeline emergencies of which the operator notifies the officials; and*

(4) *Plan how the operator and officials can engage in mutual assistance to minimize hazards to life or property.*

(d) *Each operator shall establish a continuing educational program to enable customers, the public, appropriate government organizations, and persons engaged in excavation related to activities to recognize a gas pipeline emergency for the purpose of reporting it to the operator or the appropriate public officials. The program and the media used must be as comprehensive as necessary to reach all areas in which the operator transports gas. The program must be conducted in English and in other languages commonly understood by a significant number and concentration of the non-English population in the operator's area.*

In addition to these existing standards, the Department of Transportation issued an advisory to all gas utilities during the "Great" flood of 1993. This advisory is reproduced in Appendix VIII.

3.2.2 ASME Code for Pressure Piping Gas Transmission and Distribution Piping Systems

The American Society of Mechanical Engineers Code for Pressure Piping, also referred to as ANSI Standard B31, contains some references to the protection of gas piping systems [31].

§841.13: Protection of Pipelines and Mains from Hazards

- *(a)* *When pipelines and mains must be installed where they will be subject to natural hazards, such as washouts, floods, unstable soil, landslides, or other conditions which may cause serious movement of, or abnormal loads on, the pipeline, reasonable precautions shall be taken to protect the pipeline, such as increasing the wall thickness, constructing revetments, preventing erosion, installing anchors etc.*
- *(b)* *Where pipelines and mains cross areas which are normally under water or subject to flooding (i.e., lakes, bays, or swamps), sufficient weight or anchorage shall be applied to the line to prevent flotation.*
- *(c)* *Because submarine crossings may be subject to washouts due to the natural hazards of changes in the waterway bed, water velocities, deepening of the channel, or changing of the channel location in the waterway, design attention shall be given to protect the pipeline or main at such crossings. The crossing shall be located in the more stable bank and bed locations and the depth of the line, location of the bends installed in the banks, wall thickness of the pipe, and weighting of the line shall be selected based on the characteristics of the waterway.*
- *(d)* *Where pipelines and mains are exposed, such as at spans, trestles, and bridge crossings, the pipelines and mains shall be reasonably protected by distance or barricades from accidental damage by vehicular traffic or other causes.*
- *(e)* *For offshore pipelines, consideration shall be given to the support derived from the bottom, to unstable soil conditions, and to the effect of waves, currents, marine activities, and other factors which may be detrimental to the pipeline.*

3.2.3 The American Red Cross

Although it has no legal authority, the American Red Cross plays an important role during natural disasters in providing temporary shelter, food, water and material supplies to evacuees. In addition, during the Great Flood of 1993, the American Red Cross issued public service announcements relating to public safety. It warned the public that failure to replace the safety and gas controls on flooded appliances before relighting them might lead to property damage, injury or death due to a fire or an explosion. It also called upon the public to refrain from repairing their own appliances and to defer that task to a trained professional.

3.2.4 Federal Response Plan [32]

The Federal government has the authority under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Public Law 93-288, as amended in 1988), to respond to disasters and emergencies in order to provide assistance to save lives and protect public health, safety, and property. The Federal Response Plan is designed to address the consequences of any disaster or emergency situation in which there is a need for Federal response assistance under the authorities of the Stafford Act. It is applicable to natural disasters such as earthquakes, hurricanes, typhoons, tornadoes and volcanic eruptions; technological emergency involving radiological and hazardous material releases; and other incidents requiring Federal assistance under the Act.

The Federal Response plan (FRP), administered by the Federal Emergency Management Agency (FEMA), describes the basic mechanisms and structures by which the Federal government will mobilize resources and conduct activities to augment State and local response efforts. To facilitate the provision of Federal assistance, the FRP uses a functional approach to group the types of Federal assistance which a State is most likely to need under twelve Emergency Support Functions (ESFs). Each ESF is headed by a primary agency, which has been selected based on its authorities, resources and capabilities in the particular functional area. Other agencies have been designated as support agencies for one or more ESF based on their resources and capabilities to support the functional area.

ESF #10, for example, is to provide Federal support to State and local governments in response to an actual or potential discharge and/or release of hazardous materials following a catastrophic disaster. Environmental Protection Agency (EPA) is the primary agency for ESF #10. The support agencies are:

Department of Agriculture
Department of Commerce
Department of Defense
Department of Energy
Department of Health and Human Services
Department of the Interior
Department of Justice
Department of Labor
Department of State
Department of Transportation
FEMA
General Services Administration
Nuclear Regulatory Commission

ESF #12 facilitates restoration of the Nation's energy systems following a catastrophic disaster requiring Federal response assistance. Power and fuel are critical to save lives and protect health, safety and property, as well as carry out other emergency response functions. Some of the responsibilities of this ESF include:

- Assessing energy system damage, energy supply, demand, and requirements to restore such systems;
- Administering, as needed, statutory authorities for energy priorities and allocations;
- Helping energy suppliers obtain equipment, specialized labor, and transportation to repair or restore energy systems;
- Recommending Federal actions to save fuel and electric power; and
- Providing energy emergency information, education, and conservation guidance to the public.

The Department of Energy is the primary agency for ESF #12. The support agencies for ESF #12 are:

Department of Agriculture
Department of Defense
Department of State
Department of Transportation
General Services Administration
National Communications System
Nuclear Regulatory Commission
Tennessee Valley Authority

3.2.5 Role of the Federal Emergency Management Agency (FEMA) [32,33]

FEMA is responsible for developing, exercising, and maintaining the FRP and implementing the Federal response at the national level.

FEMA may receive initial notification or warning of a disaster from multiple sources, including the National Earthquake Information Service (NEIS) of the United States Geological Survey (USGS); the National Weather Service (NWS) (including the National Hurricane Center, the Severe Storms Forecast Center and the River Forecast Center); the Office of Territorial Affairs of the Department of the Interior; the Nuclear Regulatory Commission Operations Center; the FEMA National Warning Center; a FEMA Regional Office; a State Emergency Operations Center; or the news media.

Upon the determination of the occurrence of a disaster or emergency, the FEMA National Emergency Coordination Center (NECC) will notify key FEMA headquarters and regional officials, who will in turn notify the Catastrophic Disaster Response Group (CDRG) and Emergency Support Team (EST) members at the national and regional level.

3.2.6 Comprehensive Emergency Management Plan of the States [32,33]

In case of a natural, technological or man-made disaster, if the city resources are inadequate to meet the response needs, the Emergency Management Director for the City requests assistance from the County Emergency Management Organization. If the Governor determines that state assistance is required to augment the response effort and resources of the local governments, state assistance is activated through the State's Comprehensive Emergency Management Plan. Federal assistance would supplement the state and local government resources, if needed, through the Federal Response Plan.

Each of the fifty states has its own Comprehensive Emergency Management Plan (CEMP), which establishes the framework for an effective system to ensure that they are adequately prepared for disasters and ready to respond to, recover from, and mitigate the impacts of any emergencies or disasters that might occur. The CEMP summarizes the roles and responsibilities of the state agencies, local governments and volunteer organizations.

An Emergency Support Function (ESF) approach to planning and operation, which parallels that of the federal government, is used in the state emergency management plans. Each ESF is headed by a primary agency, which has been selected based on its authorities, resources, and capabilities in the functional area. The plan also assigns specific functional responsibilities to appropriate state departments and agencies, as well as to private sector groups and volunteer organizations, which serve as the supporting agencies.

ESF #12, for example, deals with response to and recovering from fuel shortages, power outages and capacity shortages which impact or threaten to impact significant numbers of citizens and visitors. The assets available to ESF #12 are used to assist county emergency agencies and other ESFs by providing fuel, power and other resources as necessary. The primary or lead agencies coordinate with the support agencies and ESFs in directing resources and prioritizing the needs for energy restoration. Communications are maintained with gas, power, water, telephone and nuclear utilities to obtain information about damage and/or assistance needs. The procedures followed by individual utilities during energy shortages are monitored to ensure statewide action.

The Public Service Commission (PSC), the Department of Community Affairs (DCA), and the Division of Emergency Management are the primary agencies which are expected to provide resources and response support for ESF #12. As the lead agencies, the PSC and DCA, with the support agencies and ESFs, will direct resources and prioritize the needs for energy restoration. The assets available to ESF #12 are used to assist county emergency operations agencies and other ESFs with their emergency efforts to provide fuel and power and other resources as necessary.

ESF #10 provides for a coordinated, effective and efficient response to an actual or potential discharge and/or release of hazardous materials resulting from a disaster, by deploying human, financial and material resources in the affected areas. The release could occur from fixed facilities which are in use or abandoned, transportation vehicles or pipelines. The lead agency responsible for ESF #10 is the State's Department of Environmental Protection.

4. LESSONS LEARNED AND RECOMMENDATIONS

4.1 EARTHQUAKES

The Loma Prieta and Northridge earthquakes were different enough so that each provides its own unique lessons to the gas industry. The major difference was in the location of their epicenters. Loma Prieta's epicenter was at a sparsely populated area, yet its damaging effects, including failures in the natural-gas system, were concentrated at remarkably distant locations in areas of artificial and/or sandy fills. According to the U.S. Geological Survey (USGS), *".. most of the broken underground utilities, which left about a thousand homes without gas or water after the earthquake, were severed by movements associated with lateral spreading."* This occurred in San Francisco, *"..50 miles or more from the closest part of the earthquake rupture.."* in areas that include *"..fine sand fill that was hydraulically emplaced after the 1906 earthquake."* [2] Liquefaction-related ground failure was widespread throughout the San Francisco Bay Area and in the Monterey Bay Area from Santa Cruz (closer to the epicenter) to near Salinas. Further, the USGS reports that *"..areas of saturated sandy fill in San Francisco that failed in 1906 damaged the same types of structures and underground utilities that were damaged in 1989."*

4.1.1 Special Pipeline Replacement Program (SPRP)

4.1.1.1 Lessons Learned

Pipeline replacement practices are paying off. The newer plastic pipe materials performed very well. Even in the epicentral areas of Northridge, the failure rates were very small. The overall rate in PE piping was 0.03 leaks per mile compared to the system average of 0.32 leaks per mile. The Loma Prieta experience was even better. PG&E found pipeline leaks in only cast iron and steel. No leaks were found in PE piping. Of the two distribution system leaks in Palo Alto: one was in a PVC fitting (a 90-degree elbow) and the other was in a 3-inch ABS pipe.

The performance of improved girth welds in steel pipe was very good in both earthquakes.

4.1.1.2 Recommendations

Base on contacts made with the gas industry, the following recommendations are made:

1. Reassess the SPRP, and consider including transmission and distribution pipes smaller than 16-inch diameter where the pressure and location are such that they pose a high jet flame radiation potential.

2. Accelerate the replacement of pre-1930 threaded and coupled pipe, that is associated with cast-iron valves, by incorporating an appropriate risk factor in the EPOCH program for routine replacement [4].

3. Conduct geological research to improve predictions of the seismic threat [25], specifically the potential magnitudes and locations of seismically sensitive areas and the types and amounts of earth movement to be expected as a function of the geology. Suggested approaches involve additional arrays of seismic instruments to monitor the earthquake activity and geological borings to establish the subterranean composition and structure.

4. Conduct studies to optimize mitigation techniques through laboratory analysis and testing of various concepts and field testing of the most promising options. The current Parkfield tests [34,35] illustrate the field test opportunities to relate earthquake magnitude and earth motion to the stress produced in pipelines. Such tests can be expanded to evaluate the most promising designs for decoupling the pipes from the soil and/or providing pipeline flexibility.

4.1.2 Installation of Plastic Pipe

In its report [4], SoCalGas made the following recommendation: *"Evaluate the feasibility and costs associated with replacing thermal socket connections with either mechanical fittings, butt fusion, or electrofusion couplings on all new installations."*

See Appendix II for related information.

4.1.3 Meter Set Assembly and Customer Piping

4.1.3.1 Lessons Learned

Following the Northridge earthquake, SoCalGas reported that inspections were conducted on 3,486 'soft-closed' meters. Meter registration checks of 2,100 meters found 'on' indicated no leakage. However, inspections were done 3 to 4 weeks after the earthquake when damaged piping could have been repaired in the interval. Additionally, for 424 of the 2,100 meters, access was gained to the structure. This access confirmed that leakage from the gas pipes did not occur or had already been repaired. In addition, it reported that "*..there were 6,461 leaks recorded at MSAs--40% of the leaks occurred at service cocks.*"

"Approximately 7,000 leaks occurred at appliance connectors. Many were believed to be failures of semi-rigid aluminum or copper connectors which are no longer being installed."

"There were 9,000 damaged or separated gas appliance vent systems. Water heater toppling or movement was the most common problem. However, there are no known carbon monoxide fatalities due to earthquake damaged vent systems." [4]

4.1.3.2 Recommendations

SoCalGas made the following recommendations [4]:

1. *"Increase efforts to replace semi-rigid aluminum and copper connectors to appliances by educating customers during service calls."*

2. *"Conduct further studies to understand the causes of leaks at MSAs."*

See Appendix III for additional information.

4.1.4 Structural Fires and Water Heaters

4.1.4.1 Lessons Learned

In the Northridge earthquake, unstrapped water heaters accounted for 20 (39%) of the 51 structural fires that involved natural gas that were investigated by the SoCalGas task force.[4] Moreover, all structure fires where water heaters were involved, the water heaters were not strapped and/or securely restrained. The task force reported that *"...It appears some of the broken interior gas lines either supplied fuel for a fire and/or assisted in the spread of an existing fire."* It also noted that all of the toppled water heaters investigated had either collapsed or had broken legs.

In contrast, in the Loma Prieta earthquake, findings about the value of strapping water heaters were inconclusive, especially when compared to other remedies such as ensuring good ventilation and fire resistive construction of water heater enclosures. This may reflect differences either in the characteristics of the two earthquakes or in the opinions of the investigators of earthquakes [4]. No fires occurred at any "soft-closed" structures as a result of the Northridge earthquake.

4.1.4.2 Recommendations

The following recommendations were made by SoCalGas in the aftermath of the Northridge earthquake [4]. See Appendix VI for related information.

1. *"Strongly support the development/adoption of standard strapping methods that can be used by local jurisdictions so there is some consistency and validity.."*

2. *"Review the feasibility of installing an excess flow valve or quick disconnect valve on appliance connectors."*

3. *"As a possible way to increase the number of strapped water heaters, determine the feasibility of developing a quick safety check list that a service person can leave with customers whenever an unstrapped water heater is encountered. The form would identify the strapping of the heater and other safety steps to raise the awareness to the customer."*

4. *"Share our earthquake damage experience with water heater manufacturers and encourage the development of more stable features such as stronger legs or no legs."*

5. *"Work with the Office of the State Architect in developing some type of bracing for securing water heaters in enclosures."*

4.1.5 Mobile Homes

4.1.5.1 Lessons Learned

In the Northridge earthquake, *"..172 coaches were completely destroyed by fire. In many instances, fire would start at one coach and then spread to several others. In one large mobile home park, eight separate fires led to the destruction of 57 coaches. Lack of water due to broken water pipes was a contributing factor. The primary cause of the mobile home problem is the lack of seismic bracing. The coaches were knocked off their 30-inch high stands, damaging their gas pipes/MSAs."* [4]

In sharp contrast, there were no reported mobile home fires resulting from the Loma Prieta earthquake. The lesson to be learned from this difference between earthquake experiences is presently unclear.

4.1.5.2 Recommendations

In its report on the Northridge earthquake [4], SoCalGas made the following recommendations. See Appendix V for related information.

1. *"Support development of codes requiring seismic bracing."*

2. *"For new construction, MSAs should be located 4' from the coach."*

3. *"Study the feasibility of installing excess flow valves, for a fee, for customers who desire such service."*

4.1.6 Earthquake Valves

4.1.6.1 Lessons Learned

For the Northridge earthquake, SoCalGas reported that *"..Out of approximately 120,000 restores, there were 841 earthquake valves found closed and documented, for 0.7% of all restores. Tripped valves were found as far south of the epicenter as Huntington Beach; east to Claremont; north to Santa Clarita; and west to Point Dume."* [4]

There is no statistical account of earthquake valves tripped by the Loma Prieta earthquake, but both gas companies serving that area experienced large numbers of valves closed needlessly. This was attributed to public response to advice from radio and television that neglected to mention a need for such action based on broken pipes or a resident smelling a gas leak. Even in the near-epicentral region of moderately strong acceleration, only about 20 percent of the buildings *"..where service valves had been closed actually experienced some type of downstream gas pipe/appliance damage."*[36] Apparently, a much smaller fraction had developed gas leaks.

4.1.6.2 Recommendations

Following the Northridge earthquake, SoCalGas recommended that the *"Company should continue its position of supporting the customer's rights to choose earthquake valves, and to continue to oppose mandating such valves."*[4] According to Reference [37]: *"Southern California Gas Co said it plans to offer a quake safety program that would provide an earthquake-activated valve to shut off gas at the meter. If approved by the State Public Utilities Commission, the program would start on a trial basis in selected areas later this year. If successful, it could be offered in service areas in 1996. Under the program, customers would pay a one-time activation charge and a monthly fee for a two year subscription. The program would include a safety kit enabling customers to restore their own service, a once-a-year free restoration of service if the valve is activated and an annual maintenance check."*

4.1.7 Isolation Areas

Southern California Gas Company conducted an analysis to evaluate the desirability of installing earthquake sensitive automatic closing valves and remote control closing valves in the Los Angeles and Orange County areas. The estimated installation cost was $73 million with recurring overhead and maintenance costs of $1.1 million annually. The conclusions were that adding automatic closing valves would do little to increase safety and that automatic closing valves may upset system operations in areas not significantly impacted by earthquakes or after-shocks. The recommendation was that SoCalGas not install automatic closing valves. See Appendix VII for details of this analysis.

4.2 HURRICANES AND FLOODS

Based upon the various verbal and published comments made by the gas industry and DOT's Advisory Bulletin No. ADB-93-03, the following recommendations are made:

1. An effective emergency response plan addressing the worst possible natural hazards should be prepared and tested during simulated drills.

2. The emergency response plan must establish the chain of command, and compatible methods for communication between response agencies during an emergency. Rapid information exchange and organizational support enabled the timely despatch of provisions and manpower to Charleston, SC, after the storm [11].

3. The logistics needed to ensure adequate provisions must be pre-determined [11].

4. The media and the public need to be educated about actions to be taken about the gas supply in case of natural disasters [18].

5. A reliable weather tracking system should be identified and continually monitored.

6. Crisis team personnel must be identified and their responsibilities clearly defined. These teams have to be self-contained for at least 24 hours with sufficient food, water and clothing [11,16].

7. The inventories of gas equipment and supplies must be checked and replenished, if necessary. Service trucks need to be restocked as necessary for an incoming storm or during floods [11, 16].

8. The gas company's crisis management team must meet with the external emergency response teams to review public evacuation plans, locations of shelters, and to receive updates on the situation throughout the crisis. [11, 16]

9. Emergency response efforts must be coordinated with other utility companies [18].

10. To facilitate the restoration process in outlying areas which may be inaccessible after the storm, supplies and equipment including chain saws, ropes, axes, life jackets, flash lights *etc.*, must be stockpiled at various distribution sites. This would eliminate the need for driving long distances to acquire the necessary supplies. The supplies that are already available must be protected against flood and wind damage [11,15].

11. Utility companies in unthreatened neighboring states should be alerted that their help may be needed ahead of time [15].

12. Plans should be drawn ahead of time for scheduling, accommodating and feeding work crews.

13. A timely flow of information to customers is essential.

14. An underground utility locating service must be provided to all contractors, customers, and other utility companies.

15. In case of floods, all employees who may be exposed to flood water should be given tetanus and hepatitis A vaccinations or boosters.

16. Sectionalization plans for shutdown, isolation and containment must be developed by each gas company [11].

17. Backup plans for isolating sections of the pipeline must be prepared. In case of a pipeline rupture, the backup plan would involve stationing emergency response personnel at the second valves on each side of the rupture, in case the valves on either side of the rupture do not function properly [37].

18. A supply of batteries for portable telephones, emergency kits of battery rechargers must be stocked [37].

19. The accessibility of pipeline facilities, such as valve settings needed to isolate water crossings, must be evaluated [see Appendix VIII].

20. Emergency responders must be provided with maps and pipeline condition and location information [see Appendix VIII].

21. Pipeline markers and depth of cover surveys should be carried out and landowners informed about the reduced cover. Farmers should also be informed of the potential hazard of reduced cover over pipelines through agricultural agencies [see Appendix VIII and Reference 21].

22. To prevent craft operating in flooded areas from colliding with the normally-aboveground pipeline facilities that have become submerged by flood water, pipeline locations must be marked with buoys [see Appendix VIII].

23. Assistance should be requested from the Public Service Commission to transport critical materials and supplies [11, 21].

24. An ample supply of tires and fuel for vehicles must be available. Many SCE&G's vehicles had flat tires due to road debris, including roofing nails [11, 16].

25. Emergency standby generators (phones, fuel pumps, lighting, terminals etc.) need to be tested before the storm or flood [11, 16].

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APPENDICES

LIST OF APPENDICES

NOTE:

One of the objectives of the current study was to collect all available information about the Northridge earthquake effects on gas piping systems. Summarizing the information and providing a suitable reference was considered adequate for readily available reports. However, several useful documents received from Southern California Gas Company are not readily available, and were deemed useful enough for inclusion in these appendices.

APPENDIX I
STEEL PIPE PERFORMANCE DURING EARTHQUAKES
(Material copied or taken from Reference 4)

INTRODUCTION

This appendix provides additional information regarding the performance of the Gas Company's steel pipe system during earthquakes and related background material to assist in making appropriate recommendations for improvements.

STEEL PIPE PERFORMANCE

The steel pipe failures experienced as a result of the Sylmar earthquake of 1971 are shown in Table I.A for comparison with those resulting from the Northridge earthquake which are shown in Table I.B. (Data from Table 2.1 of the main body of this report.)

TABLE I.A
SAN FERNANDO-SYLMAR EARTHQUAKE
MAGNITUDE 6.6 - FEBRUARY 9,1971

- 80 Breaks in transmission lines (50 of these in line 115)
- 181 Breaks in distribution mains
- 137 Breaks in service
- 62 Breaks in service to main connections

The majority of distribution and transmission breaks occurred in old oxy-acetylene welded pipe.

TABLE I.B
NORTHRIDGE EARTHQUAKE
MAGNITUDE 6.7 - JANUARY 17, 1994

- 35 Breaks in transmission lines (25 of these in line 1001)
- 80 Breaks in distribution mains
- 74 Breaks in service

The majority of transmission breaks occurred in old oxy-acetylene welded pipe.

FIRES CAUSED BY STEEL PIPE FAILURES

Three street fires are attributed to leaks in the pipeline system. One of these occurred in the 400 block of Lincoln Boulevard in Santa Monica that involved a 12-inch distribution line (Line 40). In this case a crack occurred in a oxy-acetylene weld, 1923 vintage. The fire was apparently of very short duration and the only evidence was burn marks on the front lawn of a residence.

Another street fire occurred in Fillmore on Line 1001 at Highway 126 at the eastern city limit. This line is 12-inch diameter and the break occurred on a 1920s vintage oxy-acetylene weld. The fire lasted for about an hour with no damage to structures or other facilities.

The third street fire was widely publicized. It occurred in the 11600 block of Balboa Blvd. in Granada Hills. At this location the earthquake caused a water main to break at two locations and created two holes in Balboa Boulevard approximately 900 feet apart. The Gas Company's 22-inch transmission line (Line 120) and a 6-inch distribution main running alongside the water main also broke at these locations. Two adjacent pipelines (Lines 3000 and 3003) constructed in the mid and late 1950s and joined by arc welding, however, were not damaged.

The gas leakage from the 22-inch and 6-inch gas lines (at the 11600 block of Balboa Blvd.) resulted in an explosion and fire. No explosion or fire occurred at the other location 900 feet away where both gas lines were also broke. The explosion and fire involving the 22-inch transmission line burned five residences. This line was shut down and the resulting street fire involving the six-inch line persisted for many hours and got extensive media coverage.

Samples of Line 120 and the 6" distribution main were forwarded to Truesdail Laboratories for failure analysis. Their preliminary assessment of the failure based on visual inspection is that:

1) both failures were unrelated to workmanship,
2) there was no significant corrosion evident on the samples,
3) each pipeline absorbed a considerable amount of energy, and
4) the pipe deformed in a ductile rather than brittle manner

OXY-ACETYLENE WELDS

The recent Northridge earthquake, as well as previous earthquakes, identified weak points in the Company steel piping system. One of these weak points is old (1920s-30s) vintage oxy-acetylene welds. The Company has continued to use oxy-acetylene welding over the years for joining distribution steel piping (4" and smaller) with no significant failure trends in earthquakes except for the 1920s-30s vintage.

An assessment was made to address why the older vintage oxy-acetylene welds are more susceptible to earthquake failure than those made in subsequent years. Samples of oxy-acetylene welds that failed in the recent Northridge earthquake were analyzed and the physical properties compared to oxy-acetylene welds recently made in Welding Training.

Nearly all of the old welds submitted to us for evaluation had flaws that were rejectable by today's standards. However, the same acceptance standards did not exist at the time the piping was fabricated. For example, the first reference to radiography being used to examine welds for a west coast gas utility was at the 1940 Pacific Coast Gas Association annual meeting. A technical paper presented in 1924 (about the same time as the construction of Line 1001, which had 24 girth weld failures), stated that the common weld evaluation practice was to use an air pressure test with the pressure being equal to between two and five times the expected service pressure. In addition, a "sledge hammer test" that consisted of striking the completed weld with a "full man size swing with a 12 pound hammer" was advocated. High weld reinforcement in excess of the 1/8" maximum limit in today's standard (API 1104), was considered desirable.

Destructive examination of the welds submitted to Engineering for evaluation showed that the most consistent and severe flaws were severe lack of penetration and lack of fusion .... It was not uncommon for about one half of the thickness of the pipe to be unfused as a result of either inadequate heating of the joint or inadequate cleaning prior to welding. The weld reinforcement no doubt contributed significantly to the strength of the welds and helped compensate for the poor root penetration and fusion.

Although some lack of fusion was evident in the service tee fillet welds, the connections that failed broke through the heat affected zone at the toe of the weld on the main, and did not fail through the areas of poor fusion. Failure through the heat affected zone was the result of poor toughness often related to the excessive grain growth inherent in oxy-acetylene welds.

Butt welds in the transmission piping samples had been made both with and without chill rings (back-up rings). Where no rings were used, penetration ranged from poor to excessive. In extreme cases, the excessive penetration "icicles" could interfere with pigging operations. Where chill rings were used (i.e., arc welds on Line 104 and Line 120), either the welds did not fail, or the failures were unrelated to quality of the weld. The chill ring did not insure that the penetration was uniform or adequate, however. There were some welds in which the chill ring had broken loose from the root bead, indicating that the root bead did not penetrate into the ring.

The mechanical test data for the oxy-acetylene welds from Company piping indicate that for welds that have few significant workmanship defects, the strength of the welds is comparable to the strength of the base metal. In one sample of distribution piping, oxy-acetylene welds did not break, while two adjacent arc welds that contained more severe lack of penetration did crack.

Mechanical testing of samples of the old welds and samples of oxy-acetylene welds made recently by the staff of Welding Training showed that the tensile strength of the new welds was at least equal to, and usually greater than the strength of the old welds. In addition, the measured strength of the old welds was comparable to strength data published in the 1920s regarding the strength of oxy-acetylene welds.

Preparation of the Charpy impact test specimens for the welds was hampered by the presence of the large areas of lack of fusion and lack of penetration. However, limited testing showed that the toughness of the oxy-acetylene weld metal and heat affected zones ranged from much less to nearly comparable to the toughness of the "new" welds. Many of the poor impact results could be traced to the presence of weld flaws present in the test samples.

THREADED AND COUPLED PIPE AND CAST IRON VALVES

The recent earthquake caused some failures in steel pipe joined by threaded couplings, termed threaded and coupled (T&C). This pipe was installed in the distribution system only and the exact periods of installation are not known but are assumed to be prior to 1930.

Threaded and coupled pipe has the potential for higher leak frequency because poor or missing coatings can allow corrosion penetration into the thread areas in and adjacent to the couplings. The nature of this joint and the weakening by corrosion make it potentially vulnerable in earthquakes.

Some of the cast iron valves installed in conjunction with the T&C vintage pipe are also vulnerable in earthquakes. The Company experienced at least 7 instances where these valves fractured into two pieces. This family of pipe is not in the Special Pipeline Replacement Program. It is treated as all candidates for routine replacement. The leakage is analyzed by EPOCH and replaced as needed. Pacific Gas & Electric includes pre-1931 distribution pipe in its Gas Pipeline Replacement Program (GPRP). SoCalGas does not include this older distribution pipe in its Special Pipeline Replacement Program.

In view of the age of this pipe and potentially weak joint behavior in earthquakes, T&C pipe should be given some added priority for replacement. One way would be to continue to keep it in the routine replacement program but give it an increased risk factor in the EPOCH model to encourage more replacement of this pipe group.

How much T&C pipe is in the SoCalGas system? If we assume that all pipe 1925 and older is T&C, the total is about 12 million feet.

The T&C pipe joint has the potential to fail in earthquakes. The following table summarizes damages to different types of pipe in the 1978 Miyagi-oke magnitude 7.4 earthquake in Japan.

SIZE	JOINING METHOD	LENGTH KM	LEAKS
MAIN	ARC-WELD	241	0
	CAST IRON	586	14
	SCREW JOINT	594	204
SERVICE	SCREW JOINT	136,000(NO.)	148

No failed samples of T&C pipe were submitted to Engineering for evaluation. The samples of T&C pipe that were provided showed no evidence of cracking in the threads or of significant corrosion.

Twelve cast iron valves were provided to us, including three that had broken at the connection of the valve body to the flange. Eleven of the valves had been attached to T&C pipe; one unbroken valve had been installed in a welded pipeline. Two of the three broken valves contained internal shrinkage voids in the area of the fracture ..... The shrinkage voids may have acted as stress raisers where the fractures could more easily initiate. However, there were no flaws found in the third valve that broke. Measurements of the radius of the fillet where the valve body meets the flange showed that the radius size for modern, new valves was generally comparable to the radius size in the broken valves.

Metallographic examination of the cast iron microstructures revealed a wide range of graphite flake form, typical of a variety of compositions and pouring practices. However, even the current cast iron valve SMC, MSS SP-70, and the applicable ASTM standard require only the use of grey cast iron and do not require a specific type of graphite form toughness, or ductility. Only the tensile strength or pressure retaining capability is specified.

The 9th edition of the ASM Metals Handbook, Volume 1 states that grey cast iron is not recommended where impact resistance is required. Grey iron has considerably lower ductility than either cast steel, ductile cast iron, or malleable cast iron. For example, the tensile elongation of grey cast iron is typically about 0.6%, while the elongation for ductile cast iron may be as high as 18%. The elongation of cast steel is often greater than 20%.

A review of recent purchase requisitions shows that almost all of the gate valves currently being requisitioned by the Company are cast steel, although cast iron gate valves are still a coded item. Some cast iron valves remain in stock at the warehouse, and cast iron gate valves are occasionally installed in the field. We continue to purchase and install cast iron plug valves. Although there were some isolated instances of cast iron valve failures, they are relatively small considering the large number in service. In addition, the failures seem to be more focused in the older vintages.

The broken valves in Northern Region were in T&C pipelines. By increasing the priority for replacement of T&C pipelines in the EPOCH program, many of the high risk valves will also receive increased priority for replacement. If additional precautions against failure are desired, either the valves can be replaced with cast steel valves, or the existing valves can be encapsulated in canopies or be mechanically braced to prevent application of bending stresses on the cast iron flanges. Mechanical bracing may have the advantage that 1) the work can be performed without taking the main out of service, 2) the valve would remain accessible and operable, and 3) an appropriate design may allow installation without welding (i.e., the brace could consist of a clamp or other device that uses the existing bolt holes in the flanges for attachment).

APPENDIX II
PLASTIC PIPE PERFORMANCE
DURING THE NORTHRIDGE EARTHQUAKE
(Material copied from Reference 4)

INTRODUCTION

Since 1969, SoCalGas has installed over 14,000 miles of polyethylene (PE) main piping and in excess of 1,800,000 PE services. Prior to the use of PE, the Company installed both cellulose acetate butyrate (CAB) and polyvinyl chloride (PVC) services for brief periods of time. Although most of the CAB and PVC has been removed from ...(the) system, ... occasionally ... sections of pipe that were not replaced during the special pipe replacement programs conducted in the 1980's are (discovered).

Although all of these materials have undergone rigorous laboratory and field evaluations a lingering question remained - "How well will plastic piping systems withstand the stresses induced by a major earthquake?"

Since 1970, there have been three large earthquake events in The Gas Company's service territory: the 1971 Sylmar quake, the 1987 Whittier Narrows quake, and the Landers quake in 1972. Unfortunately none of these, for various reasons, truly tested ..(the) plastic system. However, the seismic activity on and following January 17 impacted an area of relatively high PE usage and, based on failures in our metallic piping system, generated forces that would provide a meaningful "test" of ..(the) plastic piping systems.

CONCLUSIONS

The Northridge Earthquake provided SoCalGas with its first opportunity to assess how well the plastic pipe system would withstand a major seismic event.

- 52% (14) of the reported 27 plastic failures occurred at either socket fusion's or were associated with older style transition fittings or risers.

- There were no reported failures on butt fusion joints or electrofusion couplings.

- Overall, the plastic pipe system stem performed very well, however, there is some concern that stress created during the earthquake could result in premature failures at a later date.

SoCalGas has a tracking mechanism (Plastic Leak sample Program) in place to monitor plastic pipe performance on an ongoing basis.

RECOMMENDATIONS

* Based on operating experience and failures during the earthquake, evaluate the feasibility and costs associated with using mechanical fittings, butt fusion processes, or electrofusion couplings in lieu of thermal socket couplings on all new installations.

* Use the Plastic Leak Sample Program to monitor the performance of our plastic piping system in the impacted area by comparing leak rates and failure modes in the impacted region with the balance of our system.

* Based on the excellent performance of our plastic piping system during the Northridge Earthquake, continue to support internal and external research that develops new methods, materials, and processes that extends the life expectancy and improves performance of plastic piping

DISCUSSION

Background

Our experience with plastic pipe dates back to the late 1940's with the approval of cellulose acetate butyrate (CAB) for direct burial and insert renewal of services. Both flexible and rigid CAB piping was used through the early 1950's. Ultimately, problems with the early style mechanical compression fittings used to connect the CAB to the steel piping system and a tendency for the rigid material to become brittle over time, led to the discontinued use of CAB.

In the mid-1960's, continuing improvements in polymers, various code approvals, development of ASTM specifications, and development of complete pipe and fitting systems renewed the interest in plastic piping systems by both Southern California Gas Company and its sister company, Southern Counties Gas Company.

In 1969 Southern California Gas Company began to use coiled 5/8" OD polyvinyl chloride (PVC) for insert renewal of steel services, a process that continued until 1972. Simultaneously, Southern Counties Gas Company approved polyethylene (PE) piping in 1/2" through 4" sizes for direct burial of new business mains and services.

Subsequent to the merger in 1970, a decision was made to select PE for system wide use in both new business and replacement activities. Since that time, we have added the butt and electrofusion processes to our system and approved PE pipe in 6" and 8" sizes. By the end of 1993, we had installed over 14,000 miles of PE main size piping and approximately 1,800,000 services. This equates to approximately 35% of all distribution main piping and over 50% of all services in our service territory.

Although PE resins and fitting designs have continued to improve since the early 1970's, along with new laboratory and field testing that predicts long term PE performance under stress, a lingering question remained - "How well will plastic piping systems withstand the stresses induced by a major earthquake?"

Since 1970, Southern California has experienced three significant seismic events, the 1971 Sylmar, the 1987 Whittier Narrows, and the 1992 Landers earthquakes. Unfortunately, none of these provided a true evaluation of our plastic piping systems. The 1971 Sylmar earthquake occurred well before we had any significant amount of plastic installed in our system; the 1987 Whittier Narrows earthquake did not, based on the two failures in metallic piping, generate destructive wave forms; and the 1992 Landers earthquake occurred in a sparsely populated area.

However, the seismic events occurring on January 17 centered in the Northridge area of the San Fernando Valley appears to have the components necessary to provide an "in-service" performance evaluation of our plastic piping systems during and immediately following a major earthquake. The earthquake, with a magnitude of 6.7, generated forces that, based on the failures on our metallic piping, far exceeded the stress and strains normally occurring on our plastic piping systems. In addition, the ongoing use of PE pipe for replacement in the developed areas of our system, including San Fernando Valley, and the recent new business growth in Simi Valley, Valencia, and areas of Pacific Region, provide us with a relatively good sample of early and newer generations of PE pipe.

It should be noted that the majority of the CA B and PVC piping in our system has been replaced during special programs in the mid-1980's, however, both materials are occasionally found in our system during routine replacement activities. Although this report primarily addresses PE piping, it does discuss the performance of CAB and PVC as appropriate.

Data Gathering

Immediately following the January 17 Northridge Earthquake, crews working in portions of Pacific, Northern, and Mountain View Regions began a leak survey of our underground piping system using flame ionization techniques. In total over 18,000,000 feet or 3,400 miles of distribution main piping was surveyed in the impacted areas.

While accurate pipe data has not been accumulated for the new region alignments, calculations using 1992 year end data for the old West Valley, Foothill, and South Coastal Divisions indicate that about 26% of the main piping was PE in these areas. Following that assumption, we can estimate that there .... (are) approximately 900 miles (3,400 miles surveyed x .26) of PE main size piping in the areas heavily impacted by the Northridge Earthquake.

Following the survey, there were reports of over 70 leaks that could be attributed to failures in the plastic piping system. After a careful screening of completed leak orders, a limited visual observation of physical samples, and interviews with repair crews and field supervisors, it was determined that 33 total failures may have been a direct result of the earthquake. Many of the 70 reported failures were punch tee caps, tree roots, broken stopcocks, or obvious construction defects that were either not on a plastic component or were not earthquake related.

To date we have received six PE leak samples that were removed from the impacted areas. Four of the failures occurred at multi-saddles, one occurred on 1/2" service piping adjacent to the steel portion of the transition fitting, and one occurred on a repair where a piece of PVC was "glued" into 1/2" service piping. The latter was an obvious attempt by a contractor or homeowner to repair our facilities during other construction activities and was not included in the database for earthquake related failures.

It is unfortunate that we were only able to collect a minimum number of samples, however, many failures were never uncovered as crews "bored-in" new sections of pipe in lieu of centering and excavating damaged facilities. Other samples were undoubtedly lost in the haste to move from one leak to the next in the period immediately following the earthquake.

Laboratory Analysis

All of the samples have been given to our polymer laboratory for additional documentation and evaluation. They agreed to the following deliverables: (1.) provide photographic documentation of the failures and, (2.) in the case of multi-saddles, conduct additional testing to determine the failure mode. This additional testing may determine if the failures were brittle, rapid crack failures caused by the earthquake or were existing slow growing cracks propagated to failure by rapid ground movement. They may also be able to determine if these samples failed under conditions existing prior to the earthquake.

The laboratory analysis indicates that there is no evidence to suggest that a sudden rupture occurred on any of the four multi-saddles that were evaluated and that the failures were indicative of those that we see in normal service. Based on this data we have assumed that none of the six multi-saddle failures should be attributed directly to the earthquake and concluded that only 27 leaks resulted from the earthquake.

The laboratory analysis also indicated that the 1/2 CTS pipe failure occurred as a result of rapid stretching and compression of the material at a rate of several inches per second and concluded that ground movement was the most likely cause.

Failure Analysis

Of the 27 earthquake related plastic failures, 22 (81.5%) occurred in Northern, 4 in Pacific (14.8%), and one (3.7%) in Mountain View. Interestingly, Northern completed 85.9% of the special survey conducted after the earthquake, while Pacific and Mountain View completed 5.3% and 8.8% respectively.

Exhibit A displays the 27 failures categorized by size and component. 14 of the failures occurred at either a socket fusion or adjacent to steel portions of transition fittings and risers.

Most of the failures associated with transition fittings and risers occurred on older style fittings where a PE socket connection was used adjacent to the steel transition. Modern fittings contain a plastic "pig-tail" that moves the fusion and associated stress away from the steel portion of the fitting.

The failures associated with socket connections are not unexpected. Ongoing evaluations within SoCalGas and outside research laboratories such as Southwest Research Institute or Battelle suggest that socket connections tend to concentrate stress in the fusion area. The basic design mates a rather massive fitting to a relatively thin pipe wall and requires perfect pipe preparation, alignment, and execution to make a near "stress" free joint. Socket connections require several steps within the fusion process including chamfering the pipe end, positioning the cold ring, installing and removing the heater, and joining the pipe and coupling together in perfect alignment. These steps are all completed by hand and inattention or improper techniques within the process creates stresses that can ultimately result in joint failures.

Once made, the joint must be installed "in the ditch" with perfect alignment on well compacted bedding. If not, the joint will begin to fail either through the coupling body (from the internal "notch" created during the fusion process) or through the pipe wall at the external "notch" where the pipe enters the coupling. It would be rather simple to imagine the forces that are at work on an improperly joined fitting during a major seismic event. In the case of transition fittings or risers, these forces are probably magnified by the different reaction that steel and plastic are undergoing when exposed to ground acceleration.

A review of the reported leaks on pipe indicates that most of these were not exposed as new pipe was installed and connected around the damage. We did receive one damaged ½ pipe that "buckled" and failed adjacent to the metallic portion of a transition fitting. An analysis of this failure is discussed within the laboratory analysis section.

No failures occurred on either butt fusion joints or on electrofusion processes. This was expected, as we do not see failures on these joining processes under normal conditions. Both are completed under very controlled conditions and the completed joint contains minimal stresses resulting from the fusion process.

Only one failure occurred on TR-418 compatible resin with the balance occurring on Aldyl "A" material. In addition, two anomalies were discovered, one a failure on a CAB plastic service and the other on a PE service where someone had attempted to make a repair by "gluing" a section of PVC into the service piping with PVC couplings. While these failures are not significant, the minimal numbers suggest that there are not many of these components within our system.

Slow Crack Growth

It is understood in the industry that failures resulting from slow crack growth dynamics contribute to most, if not all, of the "in-service" leaks found in PE piping systems. Although the number of leaks discovered following the Northridge Earthquake was relatively small, 0.030 leaks/mile compared to our system average of 0.32 leaks/mile. The stresses induced by ground movement into pipe and fittings could lead to premature system failures in the next few years. To determine the impact of increased failure rates, we have a process (Plastic Leak Sample Program) that will allow us to track failures and compare leak rates found within the impacted areas to rates found in the balance of our service territory.

PG&E Experience

A review of PG&E's experience during the Loma Prieta earthquake in 1989 indicated that they discovered one plastic leak on a low pressure 3" pipe installed in 1961 (PVC?). A follow-up conversation indicated that they have not seen a rise in PE failure rates in the period following the earthquake.

SUMMARY

The recent earthquake centered in the Northridge area on January 17 provided SoCalGas with its first opportunity to assess how well our plastic piping system would withstand a major seismic event. The epicenter occurred in an area that contained a relatively good proportion of PE to steel pipe and a good cross representation of the various families of PE pipe, joining processes, and components that we have used since 1969.

The initial performance of our plastic system undoubtedly exceeded our expectations and is reflective of the continuing improvements in the polyethylene industry;. Internal improvements such as improved installation procedures, enhanced training methods, and the identification of critical quality assurance criteria are directly attributable to our operating experience and results from the Plastic Leak Sample Program. Other improvements in resin design, test methods. and improved joining processes can be traced to external research agencies such as the Gas Research Institute, Battelle Laboratories, and the Southwest Research Institute or plastic pipe manufacturers.

The resulting failures were not unlike those that we experience during our normal operations. We will track system performance to determine if "in-service" failures increase as a result of stress created by the Northridge earthquake. SoCalGas is confident that existing programs will allow us to monitor the performance of our present system over time and address potential areas of concern if they should occur.

APPENDIX III
THE EFFECTS OF THE NORTHRIDGE EARTHQUAKE ON METER SET ASSEMBLIES AND CUSTOMER PIPING
(Material copied from Reference 4)

LEAKAGE ON METER SET ASSEMBLIES (MSAs)

Discussion

The 6,461 MSA leaks reported during and/or immediately following the Northridge earthquake represent 5% of the total 122,886 restores required as a result of this earthquake. This amount of leakage is understandable, especially when compared to the amount of structural damage that occurred. Under "normal" leak survey conditions, we average 1.5 MSA leaks per mile of pipe surveyed (3,400 miles / approximately 5,100 MSA leaks).

Once the Distribution piping system was operating safely and soon after the Natural Disaster Impact and Damage Analysis was complete, a questionnaire concerning MSAs was sent to the field. This questionnaire, and interviews of field personnel involved in the restore and MSA leak repair process, was conducted with the expectation of identifying any potential problem areas with the MSA gas system.

Many MSAs were damaged by outside forces and required a complete rebuild while other MSA leaks were so small that the leaks could only be found with extremely sensitive equipment. Specific parts of some leaking MSAs were replaced instead of repaired due to the state of unrest our customers felt concerning earthquakes and natural gas. This comment from the field "The customer was standing right there watching my every move" typifies the close observation service personnel experienced while trying to repair MSA leaks and restore gas service to our customers.

The following is a break down of the MSA leaks documented as a result of the Northridge earthquake:

	Total	%
MSA leaks	6.461	5% of restores (122,886)
	Breakdown	
Stopcocks	2.631	40% of MSA leaks
Insulating Bushing	906	14% of MSA leaks
Meter Swivel	714	11% of MSA leaks
Other	1,900	29% of MSA leaks

Each item is discussed below:

Stopcocks (shut-off valve)

Each MSA has a stopcock located on the riser and 40% of all the MSA leaks reported during and/or immediately following the Northridge earthquake were related to this valve. The stopcocks in the affected area are constructed of ductile iron and have two 3/4" threaded holes on either end They have a tapered, slotted brass core running through the middle. the slotted core can be rotated 90° to either "turn on" or "turn off" the flow of gas. Older stopcocks historically leak around the core when they are operated. The tapered cores are designed with a nut and large washer on the end; when leakage is detected the nut can be tightened to seat the core and stop the leakage.

Normally we would have been able to tightened the core on many of the leaking stopcocks that were replaced but due to the understandable anxiety immediately following the earthquake. service personal replaced many of the stopcocks instead of repairing them Customers did state concerns about the future operation of the stopcock, they did not want the stopcock hard to operate in the event of any future earthquakes and/or serious after shocks.

Insulating Bushings

This insulator is responsible for 14% of all MSA leaks reported during and/or immediately following the Northridge earthquake. Almost all MSAs in the affected distribution piping system have some type of insulator separating our gas system from customer owned house lines. The most common type of insulating bushing in the earthquake area is a 3/4" x 1 " nylon bushing, usually installed at the time the MSA is initially built.

Recently an employee suggestion, D93-22, was approved, changing the requirement for insulating bushings. This procedure is now in the process of being implemented (System Instruction 185.0300, MSA Installing and Rebuilding). These insulating bushings are no longer required on polyethylene/plastic services using anodeless risers or the no-stress riser adapter. Currently 99% of all services installed are polyethylene and at this time, do not require an insulating bushing. Since this System Instruction is in the process of being implemented, we do not feel a change-out program to eliminate insulating bushings is warranted as these bushings will be eliminated through MSA rebuilds and service replacements.

Meter Swivels

Leaks at meter swivels accounted for 11% of all MSA leaks reported during and immediately following the Northridge earthquake. The meter swivel is connected to the meter with a rubber washer/gasket in between. After extended periods of time in service, these gaskets dry out and with movement to the meter, they compress and leak.

These leaks are usually minimal and sometimes can be fixed by tightening the meter swivel. With customers observing and commenting on their precautious attitude towards natural gas service personnel would change the gasket and assure the customer of a leak free MSA. This is the most common type of leak found during our normal, day to day, operations.

Other

The "other" category is responsible for 29% of all MSA leaks reported during and immediately following the Northridge earthquake. This category represents all other types of leaks not documented in the previous sections. The types of leaks documented are odor complaints, falling debris, leaking gas meters, house line leaks, etc. Field interviews indicate that the two most common leaks documented in the "other" category are, 1) falling debris which damaged the MSA, and 2) leaking gas meters, each type of leak is discussed below.

Falling debris is considered shifting structures, block walls, chimneys and/or anything that can physically damage the MSA. Most of these damages resulted from situations we have no control of, an example would be retaining walls without reinforcing steel. The one change we do recommend in this area is to discourage the location of any new MSA within 6' of masonry type chimneys. This change has been made to System Instruction 185.0001. Meter Locations, and notification to the field will occur through the normal FCD process.

Our records indicate 448 gas meters were found leaking in the earthquake affected area and were replaced following the earthquake. Gas meters are designed to be positioned in a relatively level, stationary position and to mechanically measure gas through a bellows type system. They are not designed to be flexed and twisted in the manner they were subjected to during the recent earthquake. This type of movement caused some meters to begin leaking at the seams, while others were found leaking around the dial glass.

CONCLUSIONS

We believe the MSA portion of our gas system held up extremely well considering the amount of destruction observed in the earthquake affected area. The 6,461 MSA leaks, 5% of the 122,886 restores, is not considered excessive as historically we average 1.5 MSA leaks per mile of leak survey. Field personal interviewed estimated that approximately 20% of the leaks that were repaired during this period were probably there prior to the earthquake. Examples would be leaking gas meters, dial glasses and meter swivel gaskets. A recommendation, regarding MSAs, that would benefit the Gas Company and its customers is to discourage the location of any new MSA within 6' of masonry type chimneys (System Instruction 185.0001. Meter Locations).

LEAKAGE ON CUSTOMER FACILITIES

There were approximately 14,062 earthquake related leaks found on customer facilities, that were noted, out of the 288,422 disaster related orders worked. Of the leaks noted, 2,460 were houseline and 1,004 were yardline, indicating at minimum, leakage was found in the customers gas piping system 1.2% of the time.

The highest incident of earthquake related gas leaks on customer facilities were appliance connectors failing. There were 6,996 connector leaks noted, indicating at minimum, leakage was found at an appliance connector 2.4% of the time. There were 3,602 leaks noted at appliances, however, it is likely that many were connector related. Past history has shown the most common type of connector to fail is a semi-rigid aluminum or copper connector that breaks at the flair. As a result of the connector failures documented from the 1987 Whittier earthquake, the Company instituted a program to offer replacement of aluminum connectors, for a charge, when encountered on non-stationary appliances. It has been Company policy for many years to replace at no charge, copper connectors found on any gas appliance due to the potential for detonation.

APPENDIX IV
EARTHQUAKE RELATED STRUCTURE FIRES
(Material copied from Reference 4)

INTRODUCTION

There were 58 structure fires (resulting from the Northridge Earthquake), not including mobile home fires, reported to the Gas Company. As soon as all the natural gas emergencies were contained, a task force was initiated to investigate structure fires with the expectation of learning new safety measures.

SUMMARY

There is no single cause or reason responsible for the 58 structure fires (51 involving natural gas) investigated by this task force. Unstrapped water heaters accounted for 20 (39°%) of the 51 structure fires involving natural gas. Recommendations concerning improvements for this type of appliance are addressed in ....(two appendices to this report discussed later) ..... There were no additional recommendations arrived at during this investigation that would have eliminated and/or improved the structure fire situation immediately following this earthquake.

DISCUSSION

During and immediately following the earthquake, burning structure fires, some involving natural gas, could be seen in the west San Fernando Valley. During the first 24 hours following the earthquake, it is estimated that 80% of all earthquake related fires occurred. Reports of fires, some not earthquake related, continued to surface during the weeks following the earthquake. In this report, we will discuss structure fires where natural gas was involved and, which we believe, were a direct result of the January 17, 1994 earthquake.

The locations and causes of the structure fires investigated were compiled using preliminary reports from the Los Angeles City and County fire departments; additional information was gathered from Gas Company customers and other city agencies. These fires were investigated as soon as practical, however upon investigation it was found that many of the fire damaged sites had been demolished and or razed. At some of the locations, there was very little evidence available to assist us in determining the cause of the fire and at other locations, we had to rely upon the Los Angeles City Arson department for information.

All of the fires investigated were at random locations throughout Los Angeles and Ventura Counties. Of the 51 structure fires investigated that involved natural gas, 23 structures were completely destroyed and 28 structures received various levels of fire damage but were considered habitable. Regarding the 23 structures that were completely destroyed, some were apartment complexes and some were duplexes. These 23 structure fires destroyed 51 separate residences. There were also 3 street fires.

The ......earthquake ...(was) responsible for the broken water and natural gas mains in the 11000 block of Balboa Boulevard The broken high pressure 61" water main ruptured creating a large crater which revealed two broken gas lines, a high pressure (220 psi) 22" transmission line and a medium pressure (60 psi) 6" distribution line. At this location, the water main and both gas mains were separated approximately 9". There were five single family residential homes completely destroyed at this location.

A customer at the Balboa Boulevard location stated that a vehicle which was stuck in approximately 2' of water, in the middle of Balboa Boulevard, ignited the leaking natural gas. This customer also stated that the gas service stopcocks located at the five single-family residences that were destroyed, had been previously shut-off.

A few of the reported tire locations could not be located or verified from the originating source since reports taken during the first few days following the earthquake were incomplete and/or inaccurate. Some of the reported fires investigated did not involve natural gas while other locations can only be considered interior fires as no outside damage could be detected. At some locations, the only information available was from neighbors who were involved and/or witnessed the fire.

This investigation revealed that none of the natural gas related structure fires were attributed to the Gas Company's soft close policy.

The following is a breakdown of the fires investigated by this task force:

Water heaters	**20**
Other gas appliances	**08**
Broken interior gas lines (HL)	**08**
Broken MSA	**02**
Street fires	**03**
(Balboa Blvd. fire destroyed 5 homes)	
Cause unknown	**06**
Total fires	**47**

Our investigation of the 51 structure fires revealed that 39% involved water heaters; this is the only pattern observed. This task force believes there were two factors present where damaged water heaters caused and/or were involved in fires; I) an inadequate or missing water heater strapping/supporting mechanism and 2) weak or flimsy water heater legs. Each cause is discussed below:

Water Heater Strapping:

All structure fires investigated where water heaters were involved had water heaters that were not strapped and/or securely restrained. A 30 gallon water heater weighs approximately 325 pounds when fully charged. It a water heater is not adequately strapped and if it is violently shaken as in the case on January 17,1994, it can leverage itself through floors, walls and/or doors, breaking loose from all connecting hardware. When a water heater breaks loose from interior water and gas lines, it creates a hazardous condition. It appears some of the broken interior gas lines either supplied fuel for a fire and/or assisted in the spread of an existing fire.

Water Heater Legs:

Most water heaters stand in the upright position on legs designed to support the weight in a stationary position. When a water heater is fully charged and is moved or shifted as in the case during the January 17, 1994 earthquake, one or more of the supporting legs collapse and/or break, causing the water heater to topple over and break all connecting hardware. All of the destroyed water heaters observed during the investigations had either collapsed or broken legs.

Our investigation into changing the design of water heater legs has revealed that manufacturers are aware of the potential hazards of buckling water heater legs and most of the them are currently making changes. Many of the manufacturers contacted are eliminating the legs in lieu of a solid more secure base on many of their models. This change will make a water heater safer but more expensive. However, until consumer demand changes, we will continue to see the cheaper version water heaters, with legs, on the market.

CONCLUSIONS

Most of the 51 structure fires investigated were at random locations with many different scenarios involved and/or responsible for the fires. There is no explanation or main cause that can be changed to eliminate the types of fires experienced during the Northridge earthquake. Many of these fires are attributed to unstrapped water heaters and this task force believes that a higher sense of priority concerning unstrapped water heaters will result in less water heater involved fires. Recommendations concerning water heaters appear in Appendices V and VI.

APPENDIX V
THE EFFECTS OF THE NORTHRIDGE EARTHQUAKE ON MOBILE HOMES
(Material copied from Reference 4)

INTRODUCTION

Of the 92.410 mobile homes in mobile home parks throughout Los Angeles County, 4,947 were damaged (by the Northridge earthquake) with 172 mobile homes destroyed by fire, many involving leaking natural gas. This ....(Appendix) discusses gas service to mobile homes and will make recommendations to better protect gas service facilities for mobile home parks in the event of a future natural disaster such as the Northridge earthquake."

SUMMARY

We attribute most mobile home damage, including most fire damage to the fact that there was not a secure bracing system in place, and there was a lack of water with which to fight the fires. Almost all severely damaged mobile homes either slipped or bounced off the unsecured stands designed to hold them in the upright position. These mobile homes typically shifted and fell 12" to 36'' (height of the stands) to the ground. Due to the lack of an adequate bracing system to stabilize mobile homes during an earthquake mobile homes that shifted off the stands broke one or more utility connections including telephone power, gas and sewer.

The task force recommendations are based on field observations, conducted at mobile home parks immediately following the earthquake. There are five recommendations which should be taken into consideration for implementation. These recommendations include:

1) Supporting legislation involving earthquake bracing systems

2) Education programs concerning water heater strapping.

3) Locating gas meters 4' from all new mobile home installations.

4) Identify isolation points for gas piping shut-off for all mobile home parks.

5) Explain findings and concerns to all appropriate parties.

The Gas Company will continue to work with its findings and recommendations in support of regulatory agencies to improve the safety of mobile homes.

DISCUSSION

Mobile home parks are supplied with natural gas by two different types of systems, individually metered (IM) serviced by the Gas Company and/or master metered (MM), serviced by private owners, Both types of gas systems are discussed below:

Individually Metered

Each mobile home is supplied gas directly by The Gas Company which is also responsible for the natural gas piping system within the park. A Meter Set Assembly (MSA, gas meter and related piping) is located at each mobile home and the meter changing tee, located at the MSA, is considered the transition point from the Gas Company's system to the customer's system.

Master Metered

The gas company supplies gas to one or more locations, depending on the size of the park, for a master metered mobile home park. The park owner then has responsibility for the natural gas and supplies each individual mobile home. In this situation, the park owner is responsible for the installation and maintenance of the mobile home park gas system. This includes piping, meters, regulators, leakage, compliance items, etc. These systems are either operated at medium pressure, usually 5 psi, with a regulator and sub-meter installed at each mobile home and/or operated at low pressure, 7" to 10" w.c. (water column) or approximately 1/3 psi. where mobile homes can be found with or without a sub-meter. Both of these privately owned systems were found while inspecting quake affected mobile home parks.

Master metered mobile home parks are regulated by the Department of Housing and Community Development; the California Public Utilities Commission (CPUC.) administers these regulations in the State of California. The Department of Transportation, Office of Pipeline Safety Operations, regulates master metered mobile home park gas piping systems (distribution systems).

Our responsibility for master metered mobile home parks is different than individual metered parks. While the task force has considered the shut-off of natural gas at the master meter location, it is the informed opinion of Gas Company experts that this would not prevent gas in the system from supplying a substantial amount of fuel to a fire. We also believe the same recommendations that would better protect the Gas Company facilities would also benefit master metered systems. (See recommendations 1, 2 and 3).

Meter Set Assembly

The Meter Set Assembly (MSA, gas meter and pipe connections) is normally located next to the mobile home, much like a residential home. As a result of the January 17, 1994 earthquake, many mobile homes in the affected areas shifted from their locations while most residential homes stayed permanently located. Gas meters and related piping damaged by shifting mobile homes accounted for some of the natural gas fires investigated. If the location of the gas meter and related piping was outside the reach of falling or shifting mobile homes, damage to the gas meter and related piping would be considerably less. Although this task force believes the solution to the mobile home damage problem is adequate bracing, we recommend a change in Company procedures and policies relating to gas meter locations for new mobile homes in both IM and MM mobile home park. (See recommendation 3).

Riser Locations

Gas services at mobile home parks are also installed in a different manner than residential homes. Residential homes are permanently located before the gas riser is set (The gas meter is directly connected to the riser). At new mobile home parks, Gas Company crews usually find a concrete pad with a stake showing where the builder would like the gas riser positioned. In this circumstance, the crew does not know how close the final riser location will be in relation to the mobile home as the mobile home is usually moved onto the pad after all utilities have been installed. This was evident by the number of undesirable riser locations observed by this task force. Policies will be revised and/or enforced concerning locating risers and meters 4 feet from any new mobile home installation. (See recommendation 3).

Earthquake Valves

Earthquake valves, when installed on individual mobile homes, would be located on the house line side of the MSA. Current valves are built so that a specific amount of ground movement will trigger the valve and stop the flow of natural gas. During the January 17, 1994 earthquake, many mobile homes fell to the ground, either destroying and/or damaging many MSAs. At these locations, earthquake valves would not have stopped the flow of natural gas as intended since the damaged area included the location where earthquake valves would have been installed. Many of the completely destroyed mobile homes were found either resting on the MSA (IM and MM) or in the path of an out-of-control fire. Based on observations it is estimated that less than 5% of the destroyed mobile homes would have benefited from earthquake valves. These findings in no way change the Gas Company's position on earthquake valves. The Gas Company believes it should remain the customer's decision to install an earthquake valve. (See Appendix VIII for additional information.)

Excess Flow Valves

Excess flow valves (EFV) were also investigated as a means of controlling natural gas. Excess flow valves are normally installed at the service to main connection. At this time, we have approximately 90 excess flow valves under evaluation and field reports indicate further evaluation is needed due to uncertainly of operation. Until the excess flow valve is proven to be an acceptable means of controlling natural gas, this task force felt it would be premature to make any recommendations concerning these valves. In the event this valve becomes an option, the approximate cost ($700 per EFV installation) to retrofit 229,000 mobile homes with excess flow valves is estimated to be in excess of $160,300,000. This cost represent the retrofit of both individually metered and master metered mobile home parks. This cost estimate does not include the future O&M costs of maintaining and resetting excess flow valves.

Water Heaters

In many of the damaged mobile homes, water heaters were observed broken away and lying some distance from the mobile home. A 30 gallon water heater weighs approximately 325 pounds when fully charged. If a water heater is not adequately mounted and if it is violently shaken as in the January 17, 1994 earthquake, it can leverage itself through floors, walls and/or doors breaking loose from all connecting hardware. When a water heater breaks loose from interior water and gas lines, a hazardous condition maybe created. (See recommendation 2). (Also see Appendix VI for more details regarding water heater damage and means to reduce it.)

Isolation Points

Field reports indicate a concern regarding the time required to control broken gas systems in mobile home parks, both individual metered and master metered. In many cases, more than one excavation was required to locate and control gas mains and services. Because mobile home parks, as currently constructed, are very susceptible to damage from earthquakes, we recommend identification of accessible isolation points such as curb valves and/or pinch points for all mobile home parks. (See recommendation 4).

FINDINGS

At most of the locations where fire damage occurred, it appears a mobile home shifted off of its stands, severing utility connections including interior and/or exterior gas lines. Where fire occurred, the task force found that it sometimes spread to neighboring mobile homes and continued in this manner until the fire was contained. The lack of water with which to fight fires was a significant contributing factor to the amount of mobile homes destroyed (172).

There are many circumstances which contributed to the spread of the mobile home fires. Listed below are a few of the task force observations made during the first few days after the January 17, 1994 Northridge earthquake.

1. The Fire Department had many emergencies to contend with and although they made extraordinary efforts they could not be at all locations at the same time.

2. Many sections of the city were without water and this fire fighting option was not available to some mobile home parks. At the Los Olivos mobile home park, helicopter water drops were used to contain the fire.

3. Alter years of ownership, mobile home owners make use of all available space and was very little open space found. This crowded condition seems to have assisted in the spread of some fires.

4. Witness statements place wind gusts at 10 to 20 mph in a north to south direction. The direction of these wind gusts appear to have assisted with the spread of some fires in a southerly direction.

The task force has investigated many individually metered and master metered mobile home parks, with and without fire damage, in developing these recommendations. We believe that implementation of the following recommendations will lessen the risk of fire damage to mobile home parks in the event of a future natural disaster such as the Northridge earthquake.

RECOMMENDATIONS

The following recommendations are from the task force findings and should be taken into consideration for implementation:

1. Support legislation that would provide for studies necessary to consider, recommend and implement earthquake bracing and/or anchoring regulations for mobile homes.

2. Conduct an education / communication program which informs and trains mobile home owners to inspect and/or install an adequate water heater mounting system.

3. Locate the MSA 4 ft away from any new mobile home installation preferably in the front or rear of the mobile home.

4. Regions will identify available isolation points for gas piping shut-off all mobile home parks.

5. Explain findings and concerns and make recommendation 1 and 2 to all master meter mobile home park owner(s) and others as appropriate.

CONCLUSIONS

The task force reviewed many possible scenarios before making the final recommendations. These recommendations are based upon measures considered most effective for the safety of mobile home parks. The Gas Company will work with its findings and recommendations in support of regulatory agencies in improving the safety of mobile home parks.

APPENDIX VI
THE EFFECTS OF EARTHQUAKES ON WATER HEATERS AND THE EFFECTIVENESS OF STRAPPING TO RESTRAIN THEM

(Material copied from Reference 4 unless otherwise noted)

CONCLUSIONS

1. Since the adoption of the 1988 edition of the Uniform Plumbing Code, water heaters have been required to be anchored or strapped to resist earthquake motion. A statement of this requirement is also included with all new water heaters sold in California since July 1991.

2. The Office of the State Architect (OSA) provides some methods/designs for strapping water heaters. They also serve as an agency to which strapping designs can be submitted for approval.

3. Many replacement water heaters are installed by homeowners who do not take out a permit, and look for a low cost, easy to install method of strapping (usually not approved).

4. What constitutes an approved method for strapping depends on the local codes and can vary. Some standardized methods are needed for consistency among those having jurisdiction.

5. The Company recommended design (OSA approved and distributed with past bill mailings) for securing water heaters is relatively complicated, and time consuming to install. As a result customers do not utilize it very often even though it is probably the most secure design currently available.

6. Two types of water heater strapping kits were found in local hardware stores. One is approved by the OSA and is simpler than the Company design. The other is not OSA approved but is compact and lends itself for use in enclosure type installations where space is limited.

7. The strapping of a water heater by any method is a labor intensive job and the Company adopting a less complicated design will not decrease the overall cost that much.

8. The results of an employee questionnaire and field reports indicate that the most common earthquake caused damage to water heaters was water leaks, followed by loose/broken strapping, broken legs, damaged vent lines, and gas line leaks.

9. Currently available information indicates that 20 structural fires were caused by water heaters that toppled. In at least three cases (and probably more) semi-rigid gas connections were involved.

10. For water heaters in enclosures, the OSA does not offer an approved design. We reviewed these installations and felt a sturdy design is difficult because of the space restraints and lack of structural members for securing the bracing.

11. The recent earthquake identified some problems with water heater enclosures in mobile homes. This included the general lack of good structural strength of the enclosure and the difficulty in securing the water heater appropriately.

12. Excess flow valve installation at water heaters was addressed as an alternative to water heater strapping. Two models were investigated and found unacceptable largely because they were not designed for this application. Design of such an EFV will be further investigated.

RECOMMENDATIONS

1. Further study ways to strengthen the Company message to customers concerning the legal requirements to strap water heaters.

2. Strongly support the development/adoption of standard strapping methods that can be used by local jurisdictions so there is some consistency and validity.....

3. Continue to promote that new and replacement water heaters be secured using approved methods and emphasize the importance of flexible connectors for gas connections.

4. The Company consider a less costly method of strapping water heaters (a revised Company design is available but not tested, or the OSA offers a tape method, or a hardware store kit can be used).

5. Share...the Company's....earthquake damage experience with water heater manufacturers and encourage the development of more stable features such as stronger legs or no legs.

6. Work with OSA in developing some type of bracing for securing water heaters in enclosures even though no approved method exists. For the majority of cases, the bracing will provide some benefits to limit water heater movement.

7. Initiate discussions with mobile home manufacturers and appropriate standards groups to convey the structural weaknesses identified with water heater enclosures in mobile homes.

8. Pursue development of an excess flow valve for water heaters and other appliances.

DISCUSSION

Legal Requirements

The 1988 edition of the Uniform Plumbing Code requires that water heaters be anchored or strapped to resist earthquake motion. Also since July 1991, California law has required that a statement concerning the strapping requirement be included with all new water heaters sold in California. When water heaters are installed, a permit is required. Plumbers and other third-party installers will normally take out the permit and an inspector assures that the water heater is strapped in an approved manner. It is believed that homeowners are less likely to obtain permits and to secure water heaters using an approved method.

The Office of the State Architect (OSA) provides generic installation instructions intended as guides for consumers for typical installations in single family homes. These instructions do not supersede local codes. Manufacturers, public utilities, and retailers typically promote The first is the tape method which utilizes plumbers tape as a means to strap the water heater in place and which uses lag screws fastened to the studs in the adjacent walls. The second is the conduit method where the water heater is secured to the walls by rigid metal conduit piping. Both methods ..... are approved by the OSA. However, local codes can establish what constitutes an approved method and it may be different than those of the OSA. This is an area that needs standardization and there is a proposal to cover this subject for inclusion in the Uniform Plumbing Code (UPC).

Company Design

In 1990, before the OSA had issued approved methods of securing water heaters, the Company developed its own design that utilized the combination of plumbers tape and rigid conduits. The Company charges $79.00 to install the strapping of which $21.80 is materials and $57.20 is labor. This design was later tested by an outside laboratory and approved by the OSA. The Company has promoted this method of strapping in bill stuffers and a brochure given to customers when a water heater is found not strapped. The Company is currently reviewing its strapping method.

In 1992, Engineering developed an alternative water heater restrain design. This design is simpler than the current design in this it utilizes one strap (with a steel channel and brackets) instead of two. The material cost is slightly higher (about $23) but it should require less time to install (1 hour). This design has not yet been tested statically and dynamically or submitted for OSA approval.

Hardware Store Kits

Shortly after the Northridge earthquake Engineering surveyed the hardware stores for different commercially available strapping kits. The first we found was a single bracket fastened to the stud behind the water heater with two slide plates that grip the water lines on the heater. Tying the bracket to the slider plates restrains the water heater from movement. The kit retails for $6.00. This is not an OSA approved design and is best suited for installation involving space limitation, i.e., in enclosures.

The other is a more elaborate system of a metal channel, two gussets, and 28 gauge metal straps. The gussets fit in the channel that slides behind the water heater and fastens to the wall. The straps then go through the gussets and around the heater to hold it firmly in place. This unit costs $16.00, is OSA approved and has passed both static and dynamic tests.

University of California at Berkeley Study

In 1992 a study was conducted to obtain data on the extent of earthquake damage to residential water heaters, and the effectiveness of prevailing water heater restraint methods [33]. This study consisted of a survey of 299 randomly-selected people who lived in the City of Santa Cruz, California, at the time of the 1989 Loma Prieta Earthquake and a review of the rate of water-heater linked fires in the Big Bear Lake area following the 1992 Big Bear Earthquake.

The results of this study are summarized in the following. "In Santa Cruz, 13% of the respondents' water heaters suffered damage from the earthquake, most commonly water leaks... Two percent of the water heaters suffered gas leaks. No water heater related fires were reported in our sample or in the City of Santa Cruz following the earthquake (oral communication , Santa Cruz Fire Department, August 1991)... The sample revealed no quantifiable reduction in earthquake damage associated with reported prior water heater strapping with plumbers tape.

In the Big Bear Lake area 11 out of 13 structural fires were attributed to water heater gas leaks. Water heater-related fires occurred at a rate of roughly (0.6 per 1,000 structures). Further studies are needed to compare the effectiveness of different water heater restraint methods, and to identify factors that contribute to ignition in water heater related fires."

Additional details of interest are given below:

Santa Cruz

"Generalizing from our survey findings that 2% (+/- 1.6%) of the sample water heaters suffered gas leaks, suggests that in the neighborhood of 60-500 water heater gas leaks occurred in Santa Cruz without a single reported fire resulting."

Big Bear Lake

"According to fire district personnel, some of the fires involved water heaters that had been strapped with plumbers tape. In most cases, legs or supports under the water heater had failed, sometimes leading to straps being pulled out of the wall and causing cracks in flexible gas feed lines near the connection leading into the units.

"Most, if not all of the fires occurred to water heaters contained within enclosures.

General

"Possible risk factors that may increase the likelihood of water heater gas leak ignition and fire spreading include:

1. location of water heater in a small enclosure with limited ventilation

2. crimping of flexible gas lines so that they are more likely to crack when the water heater moves quickly during an earthquake,

3. presence of flammable materials nearby and

4. absence of resident from the home.

The Author's opinion is "that ordinary plumbers tape strapping should be sufficient in the majority of circumstances. The conduit method or other rigid water heater restraints may be warranted where water damage from a broken pipe would be especially costly, such as for units located near electrical equipment or on upper floors. The rigid methods may also make sense where gas leaks would pose a heightened fire risk, such as for units in mobile homes and small poorly vented enclosures. Even in these cases increasing ventilation and ensuring that enclosures are lined with fire retardant materials may be more effective ways of reducing fire risks."

Damage Reports from the Field

Operations Staff and members of Engineering who participated in the Restore effort reported that the legs on the water heater collapsing was a frequent occurrence. The cause of failure was attributed to the heaters not being strapped or having only a single strap near the top and the "up and down" motion of the earthquake. Water heaters resting on concrete floors also sustained more leg damages.

Leaks at the semi-rigid water connectors were also observed. Some of the leaks were associated with corrosion and worsened by the earthquake motion. Others were caused by the earthquake.

Twenty structural fires associated with water heater damages were reported by the Los Angeles City and Los Angeles County Fire Departments. In at least three cases, semi-rigid gas tubing connectors broke and contributed to the fire. If flexible connectors had been used, the water heater movement may not have broken the connections.

Many mobile homes in the earthquake area sustained significant damage. Potential problems were also identified with the enclosures for water heaters in these mobile homes. In some cases, the water heaters crashed through the floor of the enclosures apparently the result of initially being thrown upward by the earthquake. Many water heaters were also thrown completely out of the enclosure. A stronger enclosure would help in preventing this type of damage. More extensive use of flexible connectors for the gas connections would also have helped.

Employee Survey Results

To obtain additional data on the extent of earthquake damage to residential water heaters, Engineering surveyed 114 employees living in the affected areas at the time of the Northridge quake. Among the respondents (Table 1), 77 had the water heater in the garage and 37 in enclosures. Sixty-seven had their water heater secured in some way prior to the earthquake. There was no significant difference in the proportion of damaged and undamaged water heaters that were reported to have been secured or in enclosures.

In all, 46 households reported sustaining damages of some kind. The most common type of damage was leakage in water lines (Table 2). Other types of damages included loose or broken strap, broken heater legs, disconnected vent lines, and gas line leaks.

TABLE 1: SUMMARY OF DAMAGES TO WATER HEATERS

	DAMAGED # (%)	UNDAMAGED # (%)	TOTAL
ALL WATER HEATERS	46 (40.4)	68 (59.6)	114
IN ENCLOSURE	18 (48.6)	19 (51.4)	37
SECURED	6 (46.2)	7 (53.8)	13
UNSECURED	12 (50.0)	12 (50.0)	24
OUTSIDE ENCLOSURE	28 (36.4)	49 (63.6)	77
SECURED	22 (40.7)	32 (59.3)	54
UNSECURED	6 (26.1)	17 (73.9)	23

TABLE 2: TYPES OF WATER HEATER DAMAGES SUSTAINED DURING EARTHQUAKE

	Secured	Unsecured	Total
Water line leak	12	14	26
Gas line leak	4	3	7
Vent line loose	7	2	9
Strap/bracket loose or damaged	15	N/A	15
Heater damage	4	4	8

Water Heaters in Enclosures

Enclosed water heaters are commonly found in mobile homes and apartments. From data gathered from this earthquake, there is no evidence to indicate that enclosed water heaters are more susceptible to damages. The OSA does not address enclosed installations in the bulletin on earthquake bracing. The tight space and, in many cases, the lack of structural members make securing water heaters difficult.

We believe that any type of bracing such as brackets holding down the water heater will reduce movement and will likely reduce the damages in an earthquake. Reinforcement to the enclosure door may also be appropriate to limit water heater displacement. There were a number of reports that the water heater tipped and knocked the closet door opened.

Alternatives to Strapping the Water Heaters

Besides strapping the water heater, earthquake valves or excess flow valves (EFVs) may be used to stop gas flow into the house or the water heater in the event of an earthquake. Engineering tested two low-pressure EFVs: one from UMAC and the other from Mallard Products. Neither valve proved suitable for the application. The UMAC valve had a trip flow that exceeded most house line capacities, and the Mallard valve could not be tripped with house line pressure.

However, in concept a properly designed excess valve may serve to protect the gas line from a full break even though a complete line break is an unlikely event. These EFV'S cost about 10-20 dollars. If an EFV can be developed, it can potentially offer an inexpensive method (compared to strapping) for reducing the fire hazard caused by water heaters toppling during an earthquake.

Findings

Common sense indicates that any type of bracing should reduce water heater movement during an earthquake and hence provide some reduction of the potential damage. However, there is no evidence that shows rigid restraints are more effective than an installation with plumbers tape and flexible connectors.

Plumbers tape is used in many strapping methods and was tested to determine its strength. Engineering tested the 3/4", 24-gauge plumbers tape for tensile strength at strain rates ranging from .1 in/min to 20 in/min. The ultimate strength of the tape varied between 650 to 750 lb and exceeded the UBC requirement for Zone 4 assuming the typical residential water heater is 50 gallons or less.

Compared to other methods of strapping, the Company design is the most elaborate and requires more time to install. It also is the strongest design and has withstood static and dynamic tests. When considering different strapping methods, customers appear to look for ease of installation and cost. For this reason the popular strapping method is just plumbers tape or a hardware store kit. The Company could elect to go to a simpler design using plumbers tape, a hardware store kit, or the Company alternate design, but the overall cost for installation will probably not drop much because all the methods are labor intensive. If one of these methods was adopted, the new 1994 estimated cost of strapping could be reduced from about $125 to about $100, which is probably still not attractive enough for most customers. There may also be some increased risk associated with these other methods because they appear to be not as strong.

Water heaters installed in enclosures present a different problem. Because of the lack of space, typical installation methods described by OSA are not applicable. Any method of bracing should restrict water heater movement and reduce the probability of extensive damages. We should work with the OSA to develop some strapping methods for water heaters in enclosures.

APPENDIX VII
ISOLATION OF PIPELINES IN THE L. A. BASIN AREA DURING EARTHQUAKES

(Material copied from Reference 4)

INTRODUCTION

The earthquake of January 17, 1994 has once again opened the question concerning the safe operation of the high pressure transmission and distribution supply lines within the L. A. Basin area. Of particular interest is the possibility of automatic or remote closing of main line valves within the Basin area when major emergencies arise. The thought is that by quickly closing these valves and isolating sections of the gas system would prevent or minimize damage caused by escaping gas and or prevent fires associated with escaping gas due to pipeline ruptures. The issues of implementation, costs, practical application and impact to the system operation of closing main line valves are addressed in the following text.

CONCLUSIONS AND RECOMMENDATIONS

* Cost to add earthquake sensitive automatic closing valves and remote control closing valves in the L.A. and Orange County areas are $73 million.
* Recurring O & M cost are $1.1 million annually.
* Adding automatic closing valves would do little to increase safety.
* Automatic closing valves may upset system operations in areas not significantly impacted by earthquake or after shocks.
* It is recommended that the Company not install automatic closing valves.

IMPLEMENTATION

To determine the approximate cost of reducing the hazards of escaping gas by closing main line valves to isolate areas of the piping system during an earthquake some assumptions about how to accomplish were made. The arrangement selected is to remotely or telemetrically operate 250 valves on the transmission backbone lines from Gas Control with the balance of the valves (3035) being set to operate on some kind of automatic sensing such as pressure drop or vibration waves from ground movement. Because the transmission backbone lines move large quantities of gas from storage and out of state supplies, arbitrary or inadvertent closing of these valves could cause unnecessary outages to customers and areas within the L. A. Basin unaffected by an earthquake. Selective valve closing through system analysis, utilizing telemetric information and communication equipment would reduce the impact on areas unaffected by an earthquake. The 250 valves that would be remotely operated is a subjective choice of valves in the The 250 valves that would be remotely operated is subjective choice of valves in the Los Angeles Basin and Orange County areas. The valves selected are those that could seriously impair the operation of the system by indiscriminate closure, especially those lines associated with withdrawal from storage field, high volume customers such as U.E.G.s and gas routing facilities such as City Gates.

The remaining valves (3,035) that are set on local sensing devices would close near the highest earthquake activity. While fewer valves could be selected to close automatically, the effectiveness of isolating the piping system may be lost due to increasing the distance between valves equating to more line pack or gas in the pipe.

COST SUMMARY

Referring to the attached cost information from Engineering and the Transmission and Storage Operations Department, the installation costs to automate 3035 valves would be approximately $47 million. These figures did not reflect any type of sensing devices that would detect a variable such as pressure drop or vibration waves.. The added device increases costs by approximately $9 million and brings the estimated total to $56 million.

To remotely control 250 large diameter valves from Gas Control would add another $ 17 million assuming option #3 from the attached information to bring the total installation costs to approximately $73 million.

Total number of valves involved:	Transmission	1,906
	Distribution	1,379
	Total	3,285
Valves to be automatic:		3,035
Valves to be remotely controlled:		250

Installation Costs of Automatic Closing Valves:

Total equipment cost of actuators and vaults	$38.360,600
Total installation labor cost of actuators and vaults @ $3500 per site (2,378 sites).	$ 8,323,000
Total installation labor cost of actuators without vaults @ $500 per site (657 sites).	$ 328,500

Approximate cost of sensing unit to cause activation @ \$3000 per site (3,035 sites) either pressure rate of drop or vibration wave.	\$ 9,105,000
	\$56,117,100

Installation Costs of Remotely Operated Transmission Valves:

Total equipment cost of actuators and vaults	\$13,403,500
Total installation labor cost of actuators and vaults (@ \$3500 per site (250 sites).	\$ 875,000
Remote control from Spence Station of 250 large diameter valves using option #3 from Transmission cost estimate.	\$ 2,640,000
	\$16,918,500
Total All Installation Costs	**\$73,035,600**

Annual Operating and Maintenance Costs

Actuators and vaults	\$ 854,230
Remote control and telemetric equipment	\$ 300,000
	\$1,154.230

PRACTICAL APPLICATION CONCERNS

1. Pipeline Pack:

The reasoning behind isolating the pipeline system in the L. A. Basin is to reduce the potential damage that could be caused by high pressure or fire from escaping gas.

The spacing of large diameter pipeline valves (12" through 36") in the Basin area generally vary between I to 5 miles. The pressure in these lines typically ranges between 300 and 400 psi. The amount of gas in a I mile segment of 30" pipe operating at 350 psi is a little more than ½ million cubic feet and in a 5 mile section approximately 3 million cubic feet.

Assuming that valves were *already closed* or closed immediately upon sensing an earthquake, the energy from the pressure in the pipe would cause surface damage to streets should a rupture occur. If ignition occurs, the volume of gas would cause flame radiation large enough to endanger nearby structures and would continue to bum until the line pack is dissipated.

Automatically or telemetrically closing valves will prevent excessive loss of product and continuing fueling of a fire but does not significantly reduce the immediate risk of pressure damage or fire should a line fail.

2. Resetting Closed Valves

The valves must be reset after the initial earthquake. This will most likely need to be accomplished at a time when personnel resources are at a premium and are needed to restore customers gas service, repair facilities, and make safety inspections of the gas system.

The automatic valves will also be highly susceptible to re-closures caused by "after shocks", which usually are numerous. Repeated resetting of these valves would be required.

Making an estimate that 20% of the valves within the system may need to be reset after heavy "after shocks", the cost may be $26,000 to $27,000 for each occurrence.

20% of 3035 valves = 607 valves
Time to reset + travel = 20 minutes or 1/3 hour
Total hours to reset = 202 x 2 employees due to vault work = 404 hours
404 hours x $65.01/hr = $26,264

3. Problem Recognition for Telemetric Operated Valves

Before a valve or set of valves could be closed to isolate the larger pipelines, Gas Control would have to be able to recognize that a problem existed. Whether a pressure drop, high volume rate or some other measurement, a time delay will occur before a problem is recognized, this will tend to offset any advantage that immediately isolating the system would create.

4. Impact to System Operation

When operating conditions are normal, there will be times when automatic sensors cause valves to close. This could be caused by heavy vibrations due to construction work, heavy traffic, unusual drafting of the system causing sharp pressure drops as seen during peak day send outs or city gate valve closures.

These closures could result in loss of gas to one or more customers, disruption of injection activities at storage fields, or simply cause a need to reroute gas until the closed valve or valves can be found and reset.

5. Line 120 Failure and Fire During the January 1994 Earthquake

Quoting from the "Incident Report" dated January 28,1994:

"Resulting from the earthquake, 22 inch line 120 ruptured in two locations. The first location was Balboa Blvd., approximately 500' north of Rinaldi. The second location was approximately 1000' north of Rinaldi. Subsequent to the rupture of Line 120, escaping gas was ignited by an unknown source."

The break occurred at 4:36 am on January 17, 1994 and the pipeline pressure at the time of the incident was approximately 178 psi.

North Counties and Southern Region personnel working together isolated the ruptured section of pipe by 7:00 am and blew the line down between Mile Post 92.42 and 99.44. The pipeline was completely blown down by 7:30 am taking about 30 minutes to go flat.

The pipeline was installed in 1930 with unshielded electric girth welds. The rupture occurred at two of the welds.

6. What if Line 120 had Valves that Closed Automatically?

The pipeline would have ruptured as it did and initial mechanical damage would have remained the same.

Pipeline blowdown time would have remained at 30 minutes and may or may not have ignited.

Time of gas blowing to atmosphere would be reduced by as much as two hours and twenty four minutes.

After shocks would probably re-close the valves several times and may result in lost customers.

APPENDIX VIII

DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION

ADVISORY BULLETIN NUMBER ADB-93-03

DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
ADVISORY BULLETIN NUMBER ADB-93-03

AGENCY: Research and Special Programs Administration (RSPA), Department of Transportation.

ACTION: Advisory to owners and operators of hazardous liquid and natural gas pipeline facilities in areas of flooding.

Summary: Extended periods of rain and flooding in Midwestern states have resulted in the potential for conditions that threaten the safety of pipelines. The Office of Pipeline Safety (OPS), RSPA, has issued this advisory bulletin to pipeline operators in those flood areas to advise them of measures they should consider to assure the safety of those pipelines. In particular, pipeline operators should review emergency plans to assure that they adequately cover conditions possible in the current severe flooding.

Advisory: For compliance with 49 CFR sections 192.615(a)(3)(iv) Emergency Plans and 195.402(e)(2) Emergencies, pipeline operators must develop procedures for a prompt and effective response to natural disasters including flooding. In developing and reviewing emergency plans and procedures for natural disasters, operators should consider, as applicable to their pipeline systems, each of the actions outlined below:

Preventive Actions: Operators need to be alert to conditions that may adversely affect their pipelines and should consider the following actions:

- o Be alert to areas of flooding and have personnel available for emergency response actions such as shutdown, isolation, and containment.
- o Consider extending regulator vents and relief stacks above the level of anticipated flooding as appropriate.
- o Evaluate the accessibility of pipeline facilities, such as valve settings needed to isolate water crossings or other sections of pipelines that might be jeopardized.
- o Perform frequent patrols to evaluate right-of-way conditions at water crossings during flooding and after waters subside. Determine if flooding has exposed and/or undermined pipelines as a result of forming new channels or erosion of riverbeds.
- o Coordinate with other pipeline companies in the flood area and provide personnel to emergency response centers to act as a liaison for pipeline issues. Provide maps and information on pipeline location and condition to emergency responders.

- Determine if normally aboveground facilities (valves, regulator and relief sets, etc.) that have become submerged could be struck by craft operating in flooded areas and supply maps to emergency response centers and mark with buoys as appropriate.

- Perform surveys to determine the depth of cover over pipelines and notify landowners of reduced cover. Agricultural agencies may be helpful in reminding farmers of the potential hazard of reduced cover over pipelines.

- Assure that line markers are still in place and remind contractors, highway departments, and others involved in excavation and clearing activities associated with flood clean-up of the presence of pipelines and the operating hazards that could occur due to reduced pipeline cover.

Background: Damage to a pipeline may occur as a result of additional stresses imposed on piping by undermining of the support structure and by impact and/or waterborne forces. Washouts and erosion may result in loss of support for both buried and exposed pipelines. The flow of water against an exposed pipeline may also result in forces sufficient to cause a failure. These forces are increased by the accumulation of debris against the pipeline. Reduction of cover over pipelines in farmland may also result in the pipeline being struck by equipment used in farming or clean-up operations.

Additionally, the safety of valves, regulator and relief sets, and other facilities normally aboveground, or above-water, is jeopardized when covered by water. This threat is posed, not only by operational factors, but also by the possibility of damage by outside forces, floating debris, current, and craft operating on the water. Boaters involved in rescue operations, emergency support functions, sightseeing, and other activities, are generally not aware of the seriousness of an incident that could result from their craft damaging a pipeline facility that is unseen beneath the surface of the water. Depending on the size of the craft and the pipeline facility struck, significant pipeline damage may result. Pipeline failure could occur immediately or in the future.

Issued in Washington, D.C., on JUL 29 1993

George W. Tenley, Jr.
Associate Administrator for
Pipeline Safety