Performance of Seismic Gas Shutoff Valves and the Occurrence of Gas-Related Fires and Gas Leaks During the 1994 Northridge Earthquake, with an Update on Legislation and Standards Development

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SUMMARY

Following the 1994 Northridge earthquake, the author surveyed the performance of 479 seismic gas shutoff valves (SGSVs) at 255 sites, and the responses of 15 fire departments to gas-related incidents. The locations and performances of these SGSVs during the mainshock have been mapped along with the locations of gas-related fires and areas with the most damaged buildings. Most surveyed SGSVs within 29 km of the mainshock's epicenter closed; with one exception, the closest nonactuated SGSV was over 14 km away. SGSVs prevented numerous gas-related fires or explosions, which reduced the need for water, firefighters, and other emergency services. Los Angeles-area fire departments received numerous calls reporting gas leaks, fires, and other incidents. Fire departments responded to over 1,000 reported gas leaks and at least 50 gas-related structure fires. The gas utility reported over 14,000 leaks on consumers' lines, including 162 buildings where a SGSV closed. If the earthquake had been stronger, occurred during regular business hours, or been accompanied by strong winds, many neighborhoods might have burned and lives could have been jeopardized from fire or smoke--a potential catastrophe for any seismically prone urban area. In 1995, Los Angeles adopted a law requiring an approved SGSV to be installed on all gas-serviced new construction and commercial remodels over $10,000. Los Angeles' City Council is reviewing a draft ordinance that would expand its program to include installation of an approved SGSV on all remodels over $10,000, and all transfers of ownership within one year. Los Angeles' Public Works Committee has recommended that the Building & Safety Department should start planning the best way to expand the program to include every building within the City, and explore the establishment of operational design standards that would upgrade those established by the national and California standards. A proposed new national standard for SGSVs, expected to be published in late 1997, would allow devices that are capable of reopening during an aftershock. The U.S. Consumer Products Safety Commission launched an investigation in March 1997 into the safety of all SGSVs manufactured or sold in the U.S.

INTRODUCTION

The author began collecting performance data immediately following the Northridge earthquake as a volunteer effort on behalf of two Committees of the American Society of Civil Engineers (ASCE): the Lifeline Investigations Committee of the Technical Council

on Lifeline Earthquake Engineering (TCLEE), and the Standards Committee on Earthquake Actuated Automatic Gas Shutoff Valves. Persons responsible for one or more SGSVs were asked the following questions: 1) What was the size, make, and model of the SGSV? 2) When was the SGSV installed? 3) Was the SGSV tripped by the mainshock? 4) Were there any gas leaks? 5) If the SGSV tripped before, when? 6) Was the SGSV tripped by any aftershocks?

Respondents were not asked if their SGSV(s) had automatically reopened. It could be difficult to determine whether an installed SGSV with this capability had closed and then reopened on its own during an aftershock, or simply not closed at all. By design, over 84% of the surveyed SGSVs are unable to reopen on their own; over 10,000 SGSVs that can, however, have been installed since the Northridge earthquake.

PERFORMANCE OF SGSVS

As many SGSVs as possible, regardless of make, were surveyed. Sources included: SGSV manufacturers, plumbers and plant engineers who returned questionnaires distributed at trade shows, and the author's sales files. Nine brands were included in the survey: *Dove* (2), *Engdahl* (5), *Koso* (404), *McCray* (3), *Quake Defense* (5), *Quake Master* (23), *Safe-T-Quake* (1), *Sentinel* (16), and *Sismo* (12); unknown (8). The large number of *Koso* (also known as *California*) SGSVs in the survey is primarily because the author has represented their manufacturer, Pacific Seismic Products, Inc., since 1987; but also because a majority of the installed SGSVs in southern California during the earthquake were *Kosos*. Most of the surveyed *Quake Masters* were installed in 1985--1987, when the author represented their manufacturer. Three SGSV manufacturers provided information on the performance of 22 SGSVs; two declined to participate. All the surveyed SGSVs, except for the *McCrays* and *Sentinels*, were certified by California's Office (since renamed Division) of the State Architect, which became a requirement in California in 1987. 83% of the surveyed sites were commercial, institutional, or governmental buildings; 17% were single-family dwellings, duplexes, or small apartment buildings. 42% of the *Kosos* were industrial-type valves or seismic actuators; 74% of the *Quake Masters* and 94% of the *Sentinels* were also industrial-type valves.

The Joint OES-FEMA Disaster Field Office (1995) printed a two-map set showing the locations and performances of the surveyed SGSVs, locations of gas-related fires, and areas with the most damaged buildings. One of the maps in the first edition is reproduced in Honegger (1995) and includes the first 412 SGSVs surveyed. The second edition includes the locations and performances of all 479 surveyed SGSVs, plus the locations of 260 of the 841 SGSVs that were reset by Southern California Gas Company. A third edition is expected to be finished before this Conference (EQE International, in preparation). The maps show that the closest surveyed SGSVs to the epicenter that did not close during the mainshock, with the exception of one valve in Northridge, were 14--18 km away, in the Santa Monica Mountains; most SGSVs within 29 km of the epicenter closed. The furthest surveyed SGSV from the epicenter that did not close was in Costa

Mesa (79 km). At Long Beach Naval Station (51 km), which is built on fill, all 38 SGSVs installed in 1989 closed for the first time, while in downtown Long Beach (53 km), both surveyed SGSVs did not close. Most surveyed SGSVs closed within areas where a large number of buildings were damaged.

The local utility found a gas leak in 162 of the 841 buildings for which it was requested to reset a SGSV (Southern California Gas Company, 1994). Four of the surveyed SGSVs shut off the gas to a building with a broken gas-piping system. A 3" (76-mm) SGSV shut off the gas to Santa Monica College's Arts Building, which suffered a broken gas line on the roof, and Science Building, which has been demolished (See Figures 1 and 2). A 4" (102-mm) SGSV shut off the gas at an industrial plant in Chatsworth whose gas piping broke in several places. A 3/4" (19-mm) SGSV shut off the gas to a mobilehome in Santa Clarita whose flex piping beneath it was broken in 4 places when it fell off its foundation. At CSUN, the SGSV on the campus' main line closed, as did both SGSVs at the Student Union's satellite facility, which is a block north of the Student Union building. The SGSV at the Student Union building did not close; it is the same brand as the 2 at the satellite facility that did, although its setpoints and orientation were different. The Student Union building's SGSV was installed in 1991 in an east-west direction about 1' (254 mm) above grade, on a 3" (76-mm) manifold that was braced to the western wall of a concrete-block enclosure. The Student Union's maintenance supervisor observed early on the morning of January 18, 1994, that the SGSV was open; and he is certain that no one else would have turned it back on if it had closed (Strand, 1995). The SGSV and the manifold it was installed in were removed after the survey (S. Larson, personal comm., 1997). Pacific Seismic Products, Inc., the manufacturer, examined the SGSV in June 1997, found no defects, and performed 3 shake-table tests along each horizontal axis. The average setpoints in the longitudinal direction (E-W) were 23.2% g at 1 Hz, 11.4% g at 2.5 Hz, and > 40% g at 10 Hz; in the latitudinal direction (N-S), the average setpoints were > 30% g, 13.2% g, and > 40% g, respectively.

FIGURE 1

3" (76-MM) MODEL 315-HPF *KOSO* SGSV THAT SHUT OFF THE GAS LINE TO THE ARTS BUILDING & SCIENCE BUILDING AT SANTA MONICA COLLEGE DURING THE NORTHRIDGE EARTHQUAKE

FIGURE 2

1-1/2" (38-MM), SCHEDULE 40, BLACK-IRON GAS PIPE THAT BROKE IN A THREADED AREA NEAR A COUPLING ON THE ROOF OF THE ARTS BUILDING AT SANTA MONICA COLLEGE WHEN THE HVAC UNIT ON THE RIGHT SHIFTED ABOUT 14" (356 MM)

RESPONSE OF FIRE DEPARTMENTS TO GAS-RELATED INCIDENTS

The author surveyed 15 fire departments, most of which experienced a tremendous surge in calls after the mainshock. It was impossible to record all the calls and responses due to the large volume or the failure of their computer systems with the area-wide loss of

power. Responses to reports of gas odors, gas leaks, or gas-related structure fires or explosions comprised a large portion of the recorded responses (See Table 1).

TABLE 1

FIRE-DEPARTMENT RESPONSES ON JANUARY 17, 1994

Fire Department	Gas odors & leaks: responses/leaks	Gas-related fires: buildings/mains	Total fires/ explosions	Total responses (normal number)
Beverly Hills	**?/?**	**0/0**	**1/0**	**~125 (5)**
Burbank	**61/?**	**0/0**	**1/0**	**292 (?)**
Culver City	**4/0**	**0/0**	**0/0**	**? (?)**
El Monte	**9/3**	**0/0**	**2/0**	**38 (19)**
Fillmore	**≥ 20/perhaps 10**	**1/1**	**2/0**	**~35 (3)**
Glendale	**~100/a few**	**0/0**	**0/0**	**~300 (?)**
Los Angeles	**?/?**	**38/2**	**~ 160/2**	**? (< 20%)**
Los Angeles Co.	**?/?**	**3/?**	**512 responses/?**	**1,107 (193)**
Oxnard	**?/?**	**?/?**	**0/0**	**? (?)**
Pasadena	**?/?**	**1/0**	**1/0**	**17 (?)**
Santa Monica	**330+/?**	**4/0**	**8/2**	**? (10--15)**
Santa Paula	**14/?**	**0/0**	**0/0**	**35 (5)**
South Pasadena	**15/?**	**0/0**	**0/0**	**? (?)**
Ventura	**2/1**	**0/0**	**1/0**	**49 (?)**
Ventura County	**88/ > 66**	**3/0**	**5/0**	**265 (70)**

In Fillmore, a gas line was severed near the meter when a mobilehome fell off its foundation, resulting in a total loss. Another fire, which lasted over 2 hours, started when a 15- to 30-m-high column of natural gas escaping from a break in a 6" (152-mm) main beneath Highway 126 was ignited by static electricity; ironically, the fire scorched the front of a sprinkler-system plant (Chief Askrin, personal comm., 1995).

In Los Angeles, gas-related fires occurred in 24 single-family dwellings, 5 apartment buildings, 3 businesses, and 6 mobilehome parks. Causes included broken lines to 21 water heaters, 5 trailers, 2 floor heaters, and 2 dryers; plus leaks in an attic, a kitchen, at 2 meters, and between a meter and a building. Two fires occurred prior to the meter: one where a block wall fell on a meter and another where a large main ruptured (Los Angeles Fire Department, 1994); the latter burned five homes. Two of the mobilehome-park fires burned 54 and 59 trailers; in all, 144 trailers were lost to fire in Los Angeles. Los Angeles' Fire Marshall, Chief Parsons, is concerned that if the mainshock had occurred during the middle of the day, more leaks may have been reported that needed the gas company or the fire department to respond, and that some fires would have spread into the surrounding neighborhoods (Cluff, 1994).

On the day of the mainshock--and also on the day after--the Los Angeles County Fire Department (LACFD) had a five-fold increase in the number of recorded responses, based on 20-year daily averages (See Table 2). On the fourth day after the mainshock, the total responses were down to 200% of normal.

TABLE 2

LOS ANGELES COUNTY FIRE DEPARTMENT'S RECORDED RESPONSES ON JANUARY 17-18, 1994

Date	Gas leaks & other problems: Calls/responses	Fire help: Calls/responses	EMS help: Calls /responses	Total calls/ responses (normal number)
January 17, 1994	**220/133**	**549/512**	**488/462**	**1,257/1,107 (193)**
January 18, 1994	**164/61**	**244/221**	**375/361**	**783/643 (131)**

The widespread loss of power forced the LACFD's Command and Control (CC) to switch to the Area Command (AC) mode, in which engines went from site to site. The AC never told the CC the number of responses it made, because the Initial Incident

Commander was too busy to write down any of the responses. Calls made to the Santa Clarita Sheriff's Office or the Santa Clarita EOC were also not recorded, because structural damage to their buildings forced those agencies to move to Santa Clarita's City Hall; from where they were moved again into communications trailers and tents in the parking lot when it was discovered that City Hall was damaged, too. Three mobilehome parks within LACFD's jurisdiction had fires, including one that burned 11 trailers. When the mobilehomes came down, they dropped flat and sheared the lines near the meters (Chief David Horn, personal comm., 1995).

Pasadena's single earthquake-related fire was caused by a gas leak near a stove in a restaurant; activation of the fire-sprinkler system kept the fire from spreading (D. Rosetti, personal comm., 1995). In Santa Monica, leaking gas caused 4 fires, one of which began as an explosion due to a ruptured line on the second-floor of a 10-unit apartment building, which was a total loss; 3 adjacent structures were ignited, but were saved by the local fire department. The other 3 fires were caused by leaks in a crawl space, a kitchen, and a second-floor bedroom (Chief Collier, personal comm., 1995). In Simi Valley, 3 gas-related fires were caused by a leak in the connecting pipe to a water heater, a flame from a central-heater pilot, and a water-heater pilot that ignited paper boxes that fell from shelves (Alex Sanchez, personal comm., 1995).

California's Division of Codes and Standards, Department of Housing and Community Development (1995), reported that 176 mobilehomes were burned following the mainshock. Because most of those fires were gas-related, a report by the Seismic Safety Commission, State of California (1995), recommended that a SGSV be installed on the main service line at all mobilehome parks, and that the Public Utilities Commission (PUC) conduct hearings and workshops to determine the best method for providing SGSVs for mobilehome parks and appropriate performance standards. Provisions that would have required a SGSV on the main service line at all mobilehome parks in California by the year 2000 A.D. were deleted from SB 577 before it was passed. The author believes that for mobilehome parks, the best solution is to install a SGSV not only on each park's service main, but also on the service line for each trailer, because the large volume of gas in most parks' distribution lines would still pose a hazard to trailers with damaged gas lines.

GAS LEAKS

14,062 natural gas leaks were reported in customer facilities after the Northridge earthquake (Southern California Gas Company, 1994). Southern California Gas Company's restoration efforts included 61,172 leak orders and 122,300 restores. 88% of the 150,800 outages in 3 regions were due to customers shutting off the gas themselves; 9,100 were left off due to structural damage (Cluff, 1994). FEMA processed over 400,000 claims for water-heater damage and over 700,000 claims for all gas appliances,

including stoves, furnaces, ranges, and dryers); amounts claimed ranged from minor repair to replacement (Honegger, 1995).

UPDATE ON LEGISLATION AND STANDARDS DEVELOPMENT

Los Angeles Ordinance 170641, which took effect on September 1, 1995, requires the installation of a Los Angeles-approved seismic gas shutoff valve on all gas-serviced new construction and commercial remodels valued over $10,000. It also raised the nonactuation level of 0.08 g horizontal acceleration for frequencies of 1 and 2.5 Hz, which was established by ANSI Standard Z21.70 and California State Building Standard 12-23-1, to 0.20 g, and requires each SGSV to be braced to the outside wall or foundation of the building it protects and to be warranted by its manufacturer for 30 years. To meet Los Angeles' higher nonactuation level for 1 and 2.5 Hz, manufacturers of 7 brands of Los Angeles-approved SGSVs modified their products' trigger mechanisms from what they were in April and May of 1995, when shake-table tests were performed for ASCE's Standards Committee. Those tests were done only on SGSVs that were rigidly mounted in their normal upright position; none of the SGSVs were shaken in a tilted position (Diehl, 1995).

Los Angeles' Public Safety Committee is reviewing a revised version of Ordinance 170641, which, if adopted, would increase the City's program by requiring an approved SGSV to be installed on all remodels valued over $10,000, and all transfers of ownership within one year of sale. Los Angeles' Public Works Committee recommended to the City Council that it direct the Building & Safety Department to make recommendations within ten months on the best way to expand the program to include every gas-serviced building within the City, explore the establishment of operational design standards that would upgrade those established by the national and California standards, and put manufacturers and installers on notice that the City reserves the right to upgrade the standards in the future (Alarcon, 1997). Public Works Committee Chair Richard Alarcon wants to be assured that only high-quality devices are being installed, and believes that the Building & Safety Department should be responsible for reviewing the quality of SGSVs and possible design flaws, such as the potential for reopening during an aftershock.

In connection with the development of the first ANSI standard for SGSVs, Southern California Gas Company prepared a list of 9 criteria for an ideal SGSV (Davis, 1978). Number two on its list was that:

> Once closed [a SGSV] should not be subject to being accidentally opened by the service line in which it is installed being sharply displaced from its original vertical or horizontal orientation, or by sudden changes in the upstream gas pressure whether increasing or decreasing. I.e., once the valve has closed, it should remain "locked out" until it is reset by an outside agency.

It seems odd, therefore, to find Southern California Gas Company‘s logo on SGSVs that do not meet that criteria. Southern California Gas Company’s parent, Pacific Enterprises, created a subsidiary called Energy Services (PEES), that has heavily marketed its SGSVs since September 1996, when the PUC granted the utility permission to install Los Angeles-approved SGSVs on its side of the meter, with the understanding that it would no longer sell SGSVs. Much controversy has ensued since the PUC’s ruling, primarily because of widespread complaints from within the plumbing and heating profession about the inherent unfairness of trying to compete against a monopoly, but also because of questions that have been raised about the safety of PEES’ SGSVs (California Energy Markets, 1997; Hays, 1997a; and Wartzman, 1997). In late April 1997, the PUC made a tentative decision in favor of a complaint filed on behalf of the California Association of Plumbing, Heating and Cooling Contractors that:

> By the very nature of SoCal’s monopoly position in the energy and energy services market, its access to comprehensive customer records, its access to an established billing system, and its ‘name brand’ recognition, it must be presumed that SoCal enjoys significant market power with respect to any new product or service in the energy field (Hays, 1997b).

The PUC also started a Rulemaking and Investigations Docket to consider whether any utility or any affiliate of a utility should be allowed to enter any of the unregulated services fields, where they would be competing with private contractors (Hays, 1997b).

ASCE’s Standards Committee on Earthquake Actuated Automatic Gas Shutoff Systems submitted its proposed national standard to public balloting in March and April, 1997. Three respondents each proposed a new provision that would require a SGSV to remain closed, regardless of tilt, until manually reset. Standards Committee Chair Doug Honegger believes that none of the arguments made in support of adding any of the three proposed provisions are persuasive. It remains to be seen if the rest of the Committee will express enough support for one of the proposals to require a Committee vote. If the proposed standard remains as it is, it will likely be published by the end of 1997; if it is modified, it might not be published until spring 1998, because it would have to be submitted to public balloting again (Doug Honegger, personal comm., 1997).

California’s Seismic Safety Commission has recommended that the Division of the State Architect review its SGSV-certification requirements and revise them to improve the reliability of SGSVs (Seismic Safety Commission, State of California, 1995). The Division of the State Architect will likely wait until the proposed new national standard is published before it takes any action.

The National Institute of Standards and Technology (NIST) recognizes the potential of SGSVs to reduce the number of gas-related fires, and has suggested that to better understand their short- and long-term advantages and disadvantages, NIST should encourage a partnership of interested organizations to quantify the performance of

SGSVs during past earthquakes, identify potential improvements in design or application, quantify the benefits, risks, and costs associated with SGSVs, and establish SGSV performance criteria for service and distribution lines (Chung et al, 1995).

The U.S. Consumer Products Safety Commission launched an investigation in March 1997 into the safety of all SGSVs being manufactured or sold in the United States, after it was demonstrated to them that at least two brands currently on the market can reopen themselves when tilted or shaken. The Commission is also looking into other safety aspects of SGSVs.

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