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Post-Earthquake Fire and Lifelines Workshop; Long Beach, California January 30-31, 1995 Proceedings

Riley M. Chung, Nora H. Jason, Bijan Mohraz, Frederick W. Mowrer and William D. Walton, Editors

COVER

Balboa Boulevard, City of Los Angeles, California
Following the Northridge Earthquake, January 17, 1994.

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EXECUTIVE SUMMARY

A post-earthquake fire and lifeline workshop sponsored by the Building and Fire Research Laboratory, National Institute of Standards and Technology, was held January 30-31, 1995, in Long Beach, California. The objective of the workshop was to assess technology development and research needs that will be used in developing recommendations to reduce the number and severity of post-earthquake fires. The workshop participants included leaders in the fire service; fire protection engineering; codes and standards; insurance; transportation; and water, gas, power distribution, and telecommunication utilities with experience in dealing with consequences of earthquakes. The workshop participants developed a list of priority project areas where further research, technology development, or information collection and dissemination would serve as a vital step in reducing the losses from future post-earthquake fires.

The research and development needs generated by the participants are separated into two broad categories; ignition and fire spread, and fire control. Under the category of ignition and fire spread are the research needs related to either the direct source of ignition or the first fuel ignited, as well as factors that contribute to fire spread. The category of fire control includes research needs related to systems and personnel whose functions include the control and extinguishment of fires. The following summarizes the findings of the panels by topic areas.

Ignition and Fire Spread

Although investigations are conducted following most major earthquakes, there remains a lack of knowledge concerning the causes of fires and how fires spread from building to building. A process for collecting and a clearinghouse for storing post-earthquake fire incident data need to be established. Further, a methodology should be developed specifically designed to evaluate the impact of actions intended to reduce the number of fires and control their spread. In order to reduce the potential for a post-earthquake conflagration the potential pathways for building-to-building fire spread need to be identified and practical measures to control the spread need to be developed.

Failures in power and gas distribution systems have been identified as factors contributing to the initiation of fires following past earthquakes. The technical feasibility of seismically operated shutoffs and control mechanisms should be assessed along with a cost/benefit analysis for the use of these systems. Further, guidelines for their installation and use of these devices should be developed. As a part of this analysis the susceptibility of gas leaks to ignition should be examined.

The movement of manufactured housing units during past earthquakes has caused damage to utility lines which resulted in fires. The types of manufactured housing support and anchoring which have successfully maintained the housing units during previous earthquakes should be examined and guidelines for new and retrofit installations developed.

Fire Control

Adequate and reliable water supplies are required for both manual firefighting and automatic fire sprinkler systems. Disruptions to the primary municipal water supplies have been common in past earthquakes. Seismic design standards for water supply systems should be evaluated as well as techniques for the rapid assessment and restoration of damage to systems. Further, guidelines for coordination between fire departments and water agencies need to be developed. Since municipal water supplies are often disrupted, alternative water supply sources and distribution systems should be considered. Experience gained in using rural water supplies may be beneficial.

Water based fire protection systems such as automatic sprinklers are an important feature in the fire protection design for many buildings. A database of water based system performance during past earthquakes should be established to assist in identifying causes of past failures. The adequacy of design, installation, and maintenance practices should be evaluated and recommendations for new and retrofit systems be developed. Guidelines also are required to assess the condition of systems following an earthquake to determine if they have retained their design effectiveness.

Passive fire protection systems such as fire resistant assemblies may be damaged during an earthquake even though their condition may not be readily apparent. Guidelines for evaluating the condition of passive fire protection features need to be developed.

Lifeline systems play an important role in controlling fires and handling emergencies following an earthquake. The guidelines for the installation and retrofit of lifeline systems should be reviewed and recommendations for codes and standards developed. In addition, guidelines and procedures for the rapid restoration of lifeline systems should be examined.

Emergency service personnel are unable to respond to all emergencies following a large earthquake; therefore, it is important that the public have adequate information and training to reduce the likelihood of fires starting and take actions to control their spread. Although public information material does exist, the material should be examined based on the experience gained in recent earthquakes. Citizen volunteer response teams are being trained in some areas and the experience gained should be made widely available.

Experience has shown that following earthquakes, there is frequently inadequate communication between lifeline providers and emergency service organizations. Guidelines should be developed based on the successful plans that exist in some communities. Further, since industrial facilities have specialized requirements to handle large emergencies, methods to evaluate their resource requirements and mutual aid plans should be developed.

Water supplies may be limited following an earthquake and control of large spreading fires may be difficult. The new water additives intended to enhance the firefighting capabilities of water should be examined as a means to assist in the control of building-to-building fire spread with limited resources.

Models presently available to predict fire growth within buildings do not generally have the capability to predict fire spread between buildings. Methods to accurately predict the spread of fires between buildings damaged by earthquakes should be developed to assist in developing post-earthquake fire protection strategies.

Priorities

Although the participants associated priorities with their findings and recommendations, only recommendations with high and very high priorities were considered in detail. In many cases it was difficult to distinguish the difference between high and very high. The topic areas identified as very high priorities were: post-earthquake fire ignition sources; fire spread between buildings; water supply reliability; alternative water supplies; performance of water-based fire protection systems; seismic design of lifeline systems; lifeline restoration; control mechanisms on gas distribution systems; seismic gas shutoff valves; and earthquake preparedness public education materials. The topics identified as high priority were: evaluation of passive fire protection systems; earthquake activated electrical shutoffs; support of gas appliances; manufactured housing unit anchoring; gas leak ignition; citizen volunteer response teams; guidelines for regional coordination; fire suppression resources for industrial fires; use of water based fire fighting additives; and post-earthquake fire spread models.

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POST-EARTHQUAKE FIRE AND LIFELINE WORKSHOP

Long Beach Renaissance Hotel, Long Beach, California
January 30-31, 1995

Sponsored by:
Building and Fire Research Laboratory
National Institute of Standards and Technology

AGENDA

Monday, January 30

8:00-8:30 AM	Registration
8:30-8:40 AM	Welcome - Doug Walton, National Institute of Standards and Technology (NIST)
8:40-9:00 AM	Northridge Experience - Don Manning, Chief Engineer, Los Angeles City Fire Department and Frank Borden, Assistant Chief, Los Angeles City Fire Department
9:00-9:30 AM	Kobe Experience - Charles Scawthorn, EQE International
9:30-9:50 AM	Overview of Post-earthquake Fire Issues - Doug Walton, NIST
9:50-10:20 AM	Overview of Post-earthquake Lifeline Issues - Ron Eguchi, EQE International
10:20-11:10 AM	Break
11:10-11:30 AM	Charge to Panels - Doug Walton, NIST
11:30-12:30 PM	Panel sessions: Panel 1: Russ Fleming, Chair; Tom O'Rourke, Vice Chair; Fred Mowrer, NIST Liaison Panel 2: Ronny J. Coleman, Chair; Don Ballantyne, Vice Chair; Doug Walton, NIST Liaison Panel 3: Ron Eguchi, Chair; Bill Patterson, Vice Chair; Bijan Mohraz, NIST Liaison
12:30-1:30 PM	Lunch
1:30-3:30 PM	Panel sessions reconvene
3:30-4:00 PM	Break
4:00-5:00 PM	Panel chairs present summaries
5:30-7:00 PM	No Host Reception at Long Beach Renaissance

Tuesday, January 31

8:30-8:40 AM	Charge to Panels - Doug Walton, NIST
8:40-10:30 AM	Panel sessions reconvene
10:30-11:00 AM	Break
11:00-12:00 noon	Panel sessions prepare reports
12:30-2:00 PM	Lunch
2:00-3:30 PM	Panel chairs present reports
3:30 PM	Workshop closes

1.0 INTRODUCTION

Following the January 17, 1994 Northridge earthquake in southern California, Congress passed the Emergency Supplemental Appropriations Act of 1994, P.L. 103-211, to "...support emergency requirements arising from the consequences of the January 17th earthquake in southern California." In accordance with that legislation and as part of the National Earthquake Hazards Reduction Program, the National Institute of Standards and Technology (NIST) was authorized to "study large fires caused by earthquakes and develop techniques to minimize these fires and the damage done by them."

The Building and Fire Research Laboratory (BFRL) at NIST held a workshop to obtain input from fire and utility experts with experience in dealing with consequences of earthquakes. The objective of the workshop was to identify technology development and research needs that will be used in developing recommendations to reduce the number and severity of post-earthquake fires. The recommendations will focus on concepts that would lead to the prevention of fires following an earthquake and the means to reduce the spread of fires that do occur. The recommendations will emphasize technologies with the potential for direct and near term impact on reducing the loss from fire in future earthquakes. The recommendations will include the role of water, gas, liquid fuel, electrical power, communications, and transportation lifeline systems in the ignition of fires and in the mitigation of fire spread.

The workshop participants were divided into three panel each with a panel chair and co-chair to facilitate the panel discussion. NIST staff attended each panel session to serve as a liaison and help record the findings. The membership of each panel was selected to represent a cross section of the interest areas of the participants. The panels were charged with generating technology development or research topics which would lead to reduction of the number and severity of post-earthquake fires. The panels were to identify areas in which further understanding, development or research was needed but not to develop specific recommendations for reducing the number and severity of fires.

Each of the panels was free to select their own methodology to approach the development of research topics. In general the panels started with brainstorming sessions to list as many topics as possible and then fill out the details and priorities for the most important ones. Due to the time constraints, only high priority topics were addressed by the panels.

The recommended format for topic development given to the panels was:

Title: (working title)
Need: (statement of research need)
Objective: (objective of the research - product)
Method of Implementation: (research approach)
Priority: (overall for topic - very high, high, medium, low, very low)
Effort: (estimated development or research effort)
Comments: (additional commentary)

The three panels were given the same overall charge although each was instructed to begin with a different major topic area to ensure wide overall coverage. The focus areas given to each of the panels are as follows:

Panel 1 focus topics

- Design
    - New
    - Existing
- Construction Practices
- Codes and Standards
- Pre-earthquake Inspections
- Pre-earthquake Planning
- Public Education

Panel 2 focus topics

- Post-earthquake response
    - Mitigation of fires
    - Rescue
    - Containment
    - Suppression
- Intra-agency coordination
- Allocation of resources
- Training of responders

Panel 3 focus topics

- Post-earthquake evaluation
    - Inspections
    - Occupancy permits
- Post-earthquake restoration
    - Fire protection systems
    - Prevention of additional fires
    - Temporary measures
- Rehabilitation

At the end of the first day and at the end of the workshop the panel chairs presented a summary of the progress of each panel. The topics and priorities of each of the panels were similar, although in the limited time available there were varying levels of formal development of the project statements.

2.0 WORKSHOP FINDINGS

The following are the combined findings of the three workshop panels. Although each of the panels developed a separate prioritized list of research needs, the lists had many similarities. At the end of the workshop, the three lists were presented to the participants. It was the consensus of the panel members that the lists developed by the three panels be consolidated into a single list. This combined list was developed by the NIST staff.

2.1 Post-earthquake fire ignition sources and scenarios

Need: Post-earthquake ignition sources and scenarios have been identified, but they have not been adequately confirmed and quantified following past earthquakes. Some ignition sources and scenarios undoubtedly have not been identified. If ignition sources and scenarios are not well understood, it is difficult to adequately plan for response or to implement appropriate fire mitigation strategies. Some post-earthquake response and recovery activities may be sources of additional ignitions, such as cutting and welding or electric power restoration. In previous earthquakes, critical data have not been compiled and documented adequately. Fire investigations are difficult to conduct successfully even without post-earthquake disruptions. Trained specialty teams are needed to conduct such investigations in a timely manner.

Objective: Develop a comprehensive system to rapidly identify and quantify the sources of post-earthquake fire ignitions and ignition scenarios.

Methods of Implementation:

Elements:

1. Develop a process and mechanisms for data collection and validation, including establishment of a clearinghouse for the data bases. Identify and recommend qualifications for investigators.

2. Compile and evaluate data on fire ignition sources and scenarios from recent earthquakes (within the past 25 years) primarily in the United States.

3. Develop a model to assess ignitions and fire scenarios and the impact of actions to reduce ignitions and actions to contain or suppress fires.

Priority: Very high

Effort: 3-4 person-years

Comments:

Element 1: There is a pool of people qualified to carry out these activities. For future earthquakes, appropriate preparations must be made to pre-select potential team members. Standard fire investigation procedures should be used. Rapid mobilization is critical. Clear lines of jurisdictional responsibility must be established and respected. Experience could be gained from the public and private groups who cooperate to investigate structural and lifeline damage following earthquakes. In general, these groups do not include persons trained in fire investigation, fire service operations, and fire protection engineering.

Element 2: Fire department records on fire causes are not likely to be very detailed following a significant earthquake because fire suppression and emergency response are the primary priorities following the earthquake. A checklist should be developed to aid investigators in collecting relevant data.

Element 3: Although models have been developed that predict the number of post-earthquake fires as a function of earthquake intensity and location, little work has been done on a model to examine the impact of efforts to reduce the number of post-earthquake ignitions or actions needed to contain or suppress post-earthquake fires.

2.2 Post-earthquake fire spread between buildings

Need: A significant potential for post-earthquake conflagrations exists in certain areas due to building, landscape, terrain and climatic conditions. Such areas should be identified as part of pre-earthquake planning so that appropriate preparations can be made to minimize the potential for conflagrations.

Objectives:

1. To identify the potential pathways for building-to-building fire spread and building envelope fire penetration.
2. To develop practical mitigation measures to reduce the potential for building-to-building fire spread.
3. To develop guidelines to help assess areas with respect to their conflagration potential.

Method of Implementation:

Elements:

1. Develop a catalog of materials and methods of construction for different components of the building envelope.
2. Evaluate the alternative pathways by which exterior fires may penetrate the building envelope to become interior fires. Determine the most vulnerable elements of the building envelope for different building types and fire scenarios.
3. Evaluate alternative practical mitigation measures that could be used to improve the fire performance of the most vulnerable components of the building envelope.
4. Develop guidelines to help assess areas for their conflagration potential on the basis of construction features, landscape, terrain and weather conditions.

Priority: Very high

Effort: 2-3 person-years

Comments: Many issues related to post-earthquake fire spread between buildings are the same as for wildland-urban interface (WUI) fire spread. Research in each area may be applicable to the other, so work on WUI fire spread should be reviewed for this project.

2.3 Water supply reliability

Need: The need for reliable post-earthquake water supply for fire protection and public health has been demonstrated in past earthquakes. Earthquake damage to water supply systems has been common in past. Efforts to enhance reliability have been somewhat effective, but have generally been limited to a few of the larger water systems.

Objective: Enhance the reliability of water supply systems following earthquakes.

Methods of Implementation:

Elements:

1. Implement seismic design standards and guidelines for existing and new systems for fire protection and domestic supply. Some of the issues that should be explored include:

    - welded slip joint technology (examine technologies used by the gas utilities and other industries)
    - ductile iron pipe restrained joint design
    - fault crossing design
    - methods to improve water distribution system integrity

2. Identify/develop techniques and procedures for rapidly assessing post-earthquake water system damage to assist in emergency response and the isolation of damaged pipelines and water facilities.

3. Establish procedures and guidelines for coordination among fire, water, health, gas, and power agencies.

Priority: Very high

Effort: 2 - 3 person-years or more

Comments: A number of large communities have addressed this problem. In some jurisdictions, such as San Francisco and Los Angeles, extensive efforts have been undertaken to increase the redundancy and ruggedness of the water supply system. Implementation of these elements also must address small municipal and private water agencies. In many communities, the fire department is not familiar with the vulnerability of water systems to earthquake damage. Water and fire agencies need to develop a common understanding of the water system operation.

2.4 A comprehensive guide for identification and use of alternative water supplies

Need: Following a major earthquake, water distribution systems are commonly disrupted and alternative water supplies must be relied upon to provide water for firefighting. A variety of alternative water supplies have been used in the past and issues related to the identification and use of alternative water supplies need to be assessed. Some of these issues include:

- effectiveness of tank trucks (water tenders)
- strategies for water cistern placement
- use of swimming pools and other available stored water sources
- use of fire department pumpers to transfer water between different water systems (e.g., high/low pressure) or between parts of the same system
- use of temporary above-ground water mains
- non-potable water sources and delivery systems
- access to untreated municipal water supplies

Objective: To identify and summarize issues related to the use of alternative water supplies for firefighting during post-earthquake recovery.

Method of Implementation:

Elements:

1. Identify alternative water supply sources and distribution systems, such as water tank trucks, swimming pools, alternative water supply systems, and portable water supply systems.

2. Identify the experience jurisdictions have had with alternative water supplies.

3. Summarize the issues related to the use of different alternative water supplies, including installation and maintenance costs, reliability and adequacy.

4. Examine the use of rural water supply techniques and standards.

Priority: Very high

Effort: 1 person-year

Comments: A number of jurisdictions use one or more of the techniques itemized above during post-earthquake recovery. These techniques should be critiqued and documented so that other communities can benefit from these experiences in the selection and implementation of alternative water supplies.

2.5 Performance of water-based fire protection systems

Need: In past earthquakes, some fire protection systems have performed inadequately due to failed piping systems, inadequate bracing of sprinklers and standpipes, and inadequate anchorage of suction tanks, fire pumps, controllers, batteries, and other fire protection components.

Objectives: Improve the post-earthquake performance of fire protection systems and develop tools for assessing the post-earthquake condition of systems

Methods of Implementation:

Elements:

1. Compile data on the performance of fire protection systems in past earthquakes, using available data from fire departments, insurance companies, and contractors. Consider both component performance and system performance in identifying the causes of past failures.

2. Evaluate the adequacy of current design criteria, installation and maintenance specifications.

3. Develop acceptable retrofit criteria and practices.

4. Develop guidelines for assessing the post-earthquake condition of fire protection systems.

Priority: Very high

Effort: 1 to 2 person-years

Comments: Industry studies are under way to review and revise current design criteria in light of recent earthquake experiences. A focus of this study should be primarily sprinkler systems installed before 1987. While water-based systems are the most common fire protection systems, non-water-based systems appear to have performed better in past earthquakes. Improved ruggedness of fire protection systems also would reduce water damage caused by sprinkler system leaks and the related business interruption. A guide to assist building owners and inspectors in the post-earthquake evaluation of the condition of fire protection systems would be useful.

2.6 Post-earthquake evaluation of structural and passive fire protection systems

Need: During an earthquake, passive fire protection features of a building may be damaged. These include fire resistant assemblies such as walls, floors, ceilings, columns, and the protection of openings such as doors and dampers. Alternatively, structural damage might occur and be hidden by passive fire protection features, such as spray applied fireproofing. Such damages may not be apparent to inspectors during preliminary assessment of damage. Guidelines are needed to assist inspectors in looking for and recognizing damage to structural and passive fire protection systems in buildings.

Objectives: Develop a guide to assist inspectors in the post-earthquake evaluation of damage to passive building fire protection features.

Methods of implementation:

Elements:

1. Develop a list of passive building fire protection features and the materials used.

2. Develop guidelines for evaluating the condition of passive features.

3. Develop guidelines for inspecting structural damage in systems which include fire resistant protection.

Priority: High

Effort: 1-2 person-years

Comments: The issue of structural damage that is hidden by passive fire protection features of a building arose in the Northridge earthquake. Methods are needed to permit identification and assessment of such damage. Similarly, methods are needed to permit identification and assessment of damage to nonstructural fire barrier assemblies and opening protection devices.

2.7 Seismic design of lifeline systems

Need: Following a major earthquake, lifeline systems such as municipal water supply, electrical power, communications, gas and transportation, may be needed most when they are least likely to be available. Few standards lifeline seismic standards exist. Codes, standards and guidelines should be developed for cost-effective seismic design of lifeline systems.

Objective: Develop a consolidated set of codes, standards and guidelines for the seismic design of lifeline systems based on the best available information.

Method of Implementation:

Elements:

1. Review existing codes, standards and guidelines regarding the seismic design of lifeline systems.

2. Evaluate the adequacy of existing codes, standards and guidelines in light of actual performance during past earthquakes.

3. Recommend new, or improvements to existing codes, standards and guidelines.

4. Develop a clearinghouse for information on the seismic performance of lifeline systems.

Priority: Very high

Effort: 2 - 3 person-years

Comments: In addition to standards promulgated by public utility commissions, many utilities and other companies that provide lifeline services have developed and implemented internal standards for the seismic design of lifeline systems. It would be useful to review these standards based on post-earthquake experience, then consolidate the best of these standards into a cohesive set of codes, standards and guidelines for the seismic design of lifeline systems.

2.8 Lifeline restoration

Need: Following major earthquakes, the need for safe, effective, and timely restoration of lifeline systems such as municipal water supply, electrical power, communications, gas and transportation, is critical. Improved coordination and prioritization can accelerate recovery and reduce fire and other risks to life and property both immediately following the earthquake and during the restoration period.

Objective: Promote more effective and timely restoration of lifelines.

Methods of Implementation:

Elements:

1. Identify factors that affect the timeliness and safety of lifeline restoration.

2. For individual lifeline services, identify alternative resources for rapid service restoration, such as portable water supply systems and emergency power sources.

3. Develop field guidelines/procedures for rapidly coordinating the timing for restoration of different lifelines.

4. Identify opportunities to apply Geographic Information System (GIS) capabilities to earthquake response and recovery, such as developing real-time access/egress routing for fire service and other emergency response.

5. Develop information materials for public distribution through varied media regarding the safe restoration of lifeline services

6. Develop case studies of lifeline restoration.

7. Prepare guidelines for the support and logistics of field personnel who restore lifeline services, including potable water, food, housing, money and family safety communications.

Priority: Very high

Effort: 2 to 3 person-years

Comments: There are many resources available from previous post-earthquake studies in addressing this objective. Inter-utility experience in coordinated earthquake response and several recent studies provide important resources in developing more generic materials for use in areas that have not had recent damaging earthquakes. Partnerships should be developed to carry out the elements listed above.

2.9 Earthquake-activated electric shutoff switch

Need: An earthquake-activated electric shutoff switch may have some value under at least two potential scenarios:

1. Major earthquakes can cause local disruptions to electric service, particularly in buildings sustaining serious structural damage. Such disruptions may include ground faults or short circuits that could act as potential ignition sources. An earthquake-activated electric shutoff switch could deenergize a local electrical system and thereby reduce or eliminate the potential for this scenario.

2. Major earthquakes can cause wide area electric service disruptions. At the same time, they can cause toppling of combustible goods, which may land on electrical appliances, such as ranges, space heaters, and lighting fixtures. This does not pose a risk of ignition as long as the electric service is disrupted, but may be hazardous if the electric service is restored before combustibles are removed. An earthquake-activated electric shutoff switch would deenergize a local electrical system and permit a premise to be inspected before the local system is reenergized. This scenario is thought to have been a significant cause of fires following the Kobe, Japan Earthquake in 1995.

Objective: To assess the cost-effectiveness of earthquake-activated electric shutoff switches.

Method of Implementation:

Elements:

1. Assess the risk of ignition for the two scenarios outlined above.

2. Assess the risk reduction associated with installation of earthquake-activated electric shutoff switches.

3. Assess the costs associated with installation and maintenance of earthquake-activated electric shutoff switches.

Priority: High

Effort: 1-2 person-years

Comments: While electric shutoff switches may not be available for seismic applications, shutoff switches activated by movement of objects, noise, or other input are available. Conversion of the existing technology for seismic applications may not be difficult.

2.10 Additional control mechanisms on gas distribution systems

Need: Gas service breaks are common in the aftermath of major earthquakes. Various methods to minimize the impact of such breaks need to be evaluated, including:

- placement of automatic shutoff valves on gas service connections
- additional gas control valves on distribution system
- how to quickly and safely evacuate gas lines that have been shut down

Objective: To assess the cost-effectiveness of additional control mechanisms on gas distribution systems to reduce the incidence of post-earthquake fires.

Method of Implementation:

Elements:

1. Assess the current state of technology of gas control mechanisms.

2. Assess the potential merits and difficulties associated with the different gas control mechanisms.

3. Perform a cost-benefit analysis for the different gas control mechanism technologies.

Priority: Very high

Effort: 1-2 person-years

Comments: Some gas companies may have already or may be working on procedures for isolating and evacuating gas lines in a region after an earthquake. These efforts should be reviewed as part of this project.

2.11 Seismic gas shutoff valves

Need: Seismic valves offer the potential to reduce the number of fire ignitions due to natural gas leaks. The short-term and long-term advantages and disadvantages of the performance of these valves are not well understood. The issues include criteria for design and operation, and performance of valves in past earthquakes.

Objectives:

1. Quantify the performance of seismic valves in past earthquakes. Identify potential improvements in valve design or application.

2. Quantify the benefits, risks, and costs of seismic valves, considering locations for placement of valves of various types.

Methods of Implementation:

Elements:

1. Compile, evaluate, and analyze the performance of seismically activated valves in past earthquakes in the U.S., Japan, New Zealand, and other countries.

2. Identify and evaluate alternative seismic valve technologies.

3. Develop strategies for implementing seismic shutoff valves at locations ranging from individual services to distribution systems.

4. Perform benefit/risk analysis for various seismic valve strategies, considering life and property safety.

5. Establish performance criteria for service and distribution line shutoff valves.

Priority: Very high

Effort: 1 to 2 person-years

Comments: Several organizations are currently investigating these elements, including American Society of Civil Engineers, Technical Council on Lifeline Earthquake Engineering (ASCE/TCLEE) and gas utilities. NIST should encourage a partnership of interested organizations in carrying out this research.

2.12 Support and stability of water heaters and other gas appliances

Need: Water heaters and other gas appliances can topple or slide when subjected to ground movement due to earthquakes. Movement of gas appliances can break the gas service connection, resulting in the release and possible ignition of natural gas in a building. Different methods of support to prevent movement are currently recommended, but the effectiveness of these recommendations is not clear. There is a need to evaluate the stability of installed water heaters and other gas appliances, and recommend effective means to prevent movement of appliances during earthquakes.

Objectives:

1. Identify alternative ways to prevent movement of gas appliances under earthquake conditions.

2. Evaluate the design options for improving the stability of gas appliances.

Method of Implementation:

Elements:

1. Evaluate the risks of the movement of gas appliances during an earthquake.

2. Develop specific guidelines for supporting gas appliances to prevent movement under earthquake conditions.

3. Evaluate if a certification process for the proper installation of gas appliances would be feasible and cost effective.

Priority: High

Effort: ½-1 person-years

Comments: Water heaters in particular have been identified as being associated with post-earthquake ignition scenarios. Previous studies, some sponsored by gas companies, have tried to identify the potential for this scenario. To the extent the results of these studies are available, they should be reviewed as part of this project.

2.13 The relationship between extent of gas leak and the likelihood of ignition from overhead electrical lines and other sources

Need: When leaks occur in a gas distribution system in response to an earthquake, they may be ignited by a number of different sources. There is a question regarding the likelihood of ignition from overhead electrical lines in the event of a significant gas leak in a distribution system.

Objective: To determine the likelihood of ignition of a leak in a gas distribution system.

Method of Implementation:

Elements:

1. Determine the zone within the flammability limits for gas leaks based on the gas pressure, the size of the break, and ambient weather conditions.

2. Determine the potential for different realistic ignition sources to cause ignition of a gas leak.

3. Determine the mechanisms of ignition.

Priority: High

Effort: 1 person-year

Comments: There was some sentiment expressed that we do not know how gas leaks are ignited, particularly when high pressure gas mains rupture in the vicinity of high voltage electrical lines.

2.14 Methods to retrofit manufactured housing unit anchoring

Need: Manufactured housing units (mobile homes) frequently move from their supports in response to ground movements. Such movement can result in breakage of gas and electrical service connections and has resulted in fires following past earthquakes. Methods to improve the anchorage of manufactured housing units could reduce the incidence of gas and electrical service connection breaks and consequently the incidence of post-earthquake fires in manufactured housing units.

Objectives: To identify or develop methods to anchor manufactured housing units to prevent movement and breakage of the gas and electrical service connections.

Method of Implementation:

Elements:

1. Determine the types of support and anchoring that have been susceptible to movement in past earthquakes.

2. Determine the types of support and anchoring that have been successful in past earthquakes.

3. Evaluate different retrofit methods that could be used to reduce the incidence of manufactured housing unit movement.

4. Identify the most cost-effective methods to upgrade manufactured housing unit support and anchoring.

Priority: High

Effort: ½-1 person-years

Comments: There was some sentiment expressed during the workshop discussion that methods already exist to adequately anchor manufactured housing units. They simply need to be implemented and enforced. These methods should be identified and information regarding them disseminated to manufactured housing unit residents and authorities in vulnerable areas. An ongoing study supported by the Department of Housing and Urban Development (HUD) is being conducted at NIST to develop anchorage requirements for manufactured housing units for wind and seismic loadings. The report should be available soon and can serve as a good source document for this study.

2.15 Public education materials for earthquake preparedness for fires

Need: Emergency response personnel are not able to respond immediately to every incident in the aftermath of a major earthquake. Consequently, in many cases building occupants will have to take appropriate actions to prevent the ignition of fires and in fighting incipient fires. Public information materials should be developed and disseminated using an effective medium to convey to the public the appropriate actions to be taken under different circumstances.

Objective: To disseminate pertinent self-help information to the public regarding post-earthquake fires.

Method of Implementation:

Elements:

1. Compile and critique existing information regarding post-earthquake preparedness.

2. Identify gaps in the existing materials and fill the gaps with appropriate information.

3. Identify cost-effective means for disseminating information to the public.

4. Disseminate information to the public using all appropriate media.

Priority: Very high

Effort: 1 - 2 person-years

Comments: Some earthquake preparedness information in various forms is already disseminated to the public in some regions. For example, telephone books in California contain some information on earthquake preparedness. It would be useful to assess the impact of this and other methods used to disseminate earthquake preparedness information, then to develop and disseminate information on post-earthquake fire prevention and mitigation using an effective medium.

2.16 Citizen volunteer response teams

Need: Trained citizen volunteer response teams may be able to supplement the resources of emergency response personnel following an earthquake. Such volunteers are frequently available, but may be ineffective without adequate training and equipment. The training, organization and equipment of such teams needs to be addressed.

Objectives:

1. Identify the training and equipment needs of citizen volunteer response teams.

2. Develop and document training materials for citizen volunteer response teams.

Method of Implementation:

Elements:

1. Determine the types and perceived benefits of citizen volunteer response teams that have been organized in the past in different communities.

2. Critique the previous efforts regarding citizen volunteer response teams and develop recommendations for the training, organization and equipment of such teams.

3. Develop appropriate training materials for citizen volunteer response teams.

Priority: High

Effort: 1 person-year

Comments: Citizens frequently turn out to assist emergency response personnel during major disasters. In the case of widespread demand for emergency response, citizens may need to assume a lead role in protecting their own neighborhoods. Without adequate training, organization and equipment, the activities of volunteers can be ineffective or even counterproductive. With adequate planning and preparation, it is believed that citizen volunteer response teams can be a valuable asset to emergency response efforts. Programs may already exist in some states, such as California. The status of such programs should be evaluated.

2.17 Guidelines for the regional coordination of emergency response personnel and lifeline providers

Need: Emergency response personnel and lifeline providers have different jurisdictional boundaries. The location and intensity of an earthquake will in large part determine the primary and secondary response needs for the affected communities. Guidelines are needed to assist communities in the preplanning, coordination and prioritization of response to different events. Some of the issues to be addressed include:

- How should water departments respond?
- How should other utilities respond?
- What mutual-aid arrangements may be appropriate?

Objectives: To develop guidelines for the regional coordination of efforts among emergency response personnel and lifeline providers.

Method of Implementation:

Elements:

1. Assess current efforts to coordinate emergency response personnel and lifeline providers.

2. Develop guidelines for the regional coordination of emergency response personnel and lifeline providers.

Priority: High

Effort: 1-2 person-years

Comments: The Emergency Operations Center of Los Angeles County coordinates emergency response efforts during a disaster among county agencies and utilities. Similar operations probably exist for the City of Los Angeles and other large metropolitan areas.

2.18 Guidelines to evaluate the fire suppression resources needed to fight post-earthquake industrial fires

Need: Firefighting resources may be taxed beyond their limits following a major earthquake, particularly at industrial sites. Historically, some industries have relied on shared resources to provide assistance to each other in a major event at a single facility. In a post-earthquake situation, multiple facilities may experience fires or other events that prevent such sharing of resources. Guidelines should be developed to evaluate the type and quantity of firefighting agents as well as the other resources needed to fight post-earthquake fires.

Objective: Develop guidelines to assist industrial facilities in assessing the resources needed to fight post-earthquake fires at their facilities.

Method of Implementation:

Elements:

1. Evaluate existing plans for mutual assistance in different industries.

2. Develop methods to assess the firefighting resources needed at an industrial facility.

3. Develop methods to assess the impact of an earthquake on mutual assistance plans.

Priority: High

Effort: 1-2 person-years

Comments: The nature and extent of formal mutual assistance plans among industrial facilities are not clear. This study presents an opportunity to evaluate and further develop mutual assistance plans under post-earthquake and other emergency conditions.

2.19 Assessment methods for compressed-air foam and other water additive firefighting agents intended to reduce fire spread between buildings

Need: A number of new water additive fire fighting agents are being developed with the intent of reducing fire spread between buildings. Demonstrations have been conducted to illustrate the potential uses of such agents. Scientifically valid and realistic assessment methods should be developed that will permit a more quantitative evaluation of the uses and limitations of these fire fighting agents.

Objective: Develop scientifically credible assessment methods to evaluate the performance of different firefighting agents.

Method of Implementation:

Elements:

1. Evaluate existing methods for assessing the performance of firefighting agents.

2. Determine one or more appropriate fire scenarios for evaluating different firefighting agents.

3. Develop one or more assessment methods for evaluating the performance of firefighting agents. These assessment methods may include a combination of bench-scale and large-scale tests for different fire scenarios.

Priority: High

Effort: 1-2 person-years

Comments: These assessment methods also can be used to assess the capabilities of different agents with respect to wildland-urban intermix fires. Existing assessment methods that may have been developed for such fires should be evaluated.

2.20 Fire models for earthquake-damaged buildings and building-to-building spread

Need: More accurate prediction of fire spread within and between buildings damaged by earthquakes would be of value to emergency responders in the assessment of fire suppression strategies.

Objective: Revise existing building fire models to address the effects of earthquake damage on fire spread within and between buildings.

Method of Implementation:

Elements:

1. Identify the most promising existing fire models.

2. Revise models to address the influence of earthquake damage on fire spread.

3. Integrate revisions into the existing fire models.

4. Calibrate the new models against actual post-earthquake fire experience.

Priority: High

Effort: 2-3 person-years

Comments: From the title of this topic one might infer that existing fire models adequately predict fire spread within buildings that have not suffered earthquake damage. This is not necessarily the case. Considerably more work is required to validate existing models for a range of realistic fire spread scenarios, then to add features to calculate fire spread in earthquake-damaged buildings and between buildings.

3.0 WORKSHOP PAPERS

Four presentations were given at the opening of the workshop. Don Manning, Chief Engineer, Los Angeles City Fire Department and Frank Borden, Assistant Chief, Los Angeles City Fire Department, presented an overview of the Northridge experience. Charles Scawthorn, EQE International, presented an overview of the Kobe experience. Doug Walton, NIST, presented an overview of post-earthquake fire issues. Ron Eguchi, EQE International and Riley Chung, NIST, presented an overview of post-earthquake lifeline issues.

3.1 Overview of Post-Earthquake Fire Issues

The experience following past major earthquakes has shown that fires will start as a result of the earthquake which challenge the resources of the fire service due to the number of fires, disruption of the water supply, and damage to fire protection systems within buildings. Generally the number of fires is proportional to the magnitude of the earthquake and there exists the potential for a significant loss of life and property as a result of post-earthquake fires. The loss of life and property caused by fire occurs in a time frame different from the structural and property damage caused directly by the earthquake. While most of the loss caused by shaking occurs during the time of ground movement, there is basically no fire loss during that time. Fire loss directly attributable to the earthquake begins immediately following the earthquake and can continue for days after the major ground movement has stopped.

Although there are many possible causes of fires following earthquakes some of the most common appear to be fires associated with natural gas leaks, fires caused by electrical system malfunctions, and fires caused by hazardous chemical interactions or involving flammable liquids. While natural gas leaks are not in themselves the source of ignition, natural gas is relatively easy to ignite and gas leaks pose significant fire and explosion hazard in damaged buildings. Gas leaks outside of buildings in high pressure lines have resulted in large fires which led to the ignition of adjacent structures.

Fires must be treated in a short time frame. Unlike some other search, rescue, and recovery efforts which may have successful outcomes days after the earthquake, fires caused by the earthquake will begin to spread immediately. The recent United States post-earthquake fire impact has been small due in part to good fortune. Both the Northridge and Loma Prieta earthquakes occurred when the winds were light and the humidity was relatively high. Had this not been the case, the few fires which did occur may have spread resulting in far greater losses. Fires following earthquakes occur not only in the immediate aftermath of the earthquake, but the incidence of fires generally continues at a higher than normal rate for several days. This can be attributed at least in part to fires resulting from utility restoration and cleanup efforts.

The fire service is the first line response agency for a wide range of emergency situations. Not only does the fire service handle fires but in many cases they are the primary providers of emergency medical service (EMS), urban search and rescue (USAR), response to hazardous materials spills (HAZMAT), and a wide variety of other rescue situations. Frequently following a major earthquake a large number and wide variety of emergency conditions will exist. Even the best equipped and best trained fire services in the country cannot be expected to maintain adequate staffing and equipment levels to simultaneously response to all of the emergencies during and following a major disaster.

The overall post-earthquake fire objectives are to reduce the number of ignitions and reduce the the likelihood that fires will spread. These objectives can be met by a combination of in place systems and the actions by people. Fire protection in the municipal environment is derived from private and public systems including building construction, building fire protection systems, land use, public and private water supplies, public and private fire departments, and communication and utility systems. In the aftermath of a major earthquake the normal interactions between these systems are disrupted. Even though emergency operational plans exist, the interaction between these systems in reducing the loss from fire is complex since it involves decisions on the part of a great many people.

3.2 Significant Impacts and Lessons Learned for the January 17, 1994 Northridge Earthquake, Transportation and Utility Lifelines

In the past several decades, the southern California area has been host to a series of moderate but damaging earthquakes. The most significant event was the 1971 San Fernando earthquake because it pointed out the extreme vulnerability of our cities' lifeline systems. Virtually every lifeline system in the San Fernando Valley was affected in some way, with many suffering complete collapse or failure. As a result of this earthquake, extensive planning and mitigation efforts were initiated by all utilities (Seligson et al., 1991). Not until the occurrence of the 1994 Northridge earthquake had these planning efforts been truly tested. In general, the response of lifelines in this most recent event was acceptable; however, in some cases response and recovery resources were close to being overwhelmed.

Table 1 shows a preliminary summary of observed damages and outages for some of the affected lifelines. As is evident from this table, the majority of repair costs are associated with the reconstruction of the transportation system (about $1.45 billion or 80 percent of the total). The next largest cost was associated with the repair of damaged electric power systems (over $130 million).

Utility service disruption was extensive in some cases. For the first time in Los Angeles history, electrical power was out in the entire city. Although it is not unusual for a power system to shut down part of its network in order to prevent permanent damage to critical equipment, it is unusual for an entire system to completely shut down. As will be discussed later, complete shutdown was problematic in this event because many generating facilities lacked the ability to self start once tripped off. The one positive aspect of this response; however, was that electric power service was restored to 90 percent of the Los Angeles Department of Water and Power customers within one day of the earthquake. This rapid restoration points out the significance of examining performance as a combination of measures. That is, immediate outage may be acceptable as long as restoration time is short.

This section provides a summary of significant impacts and lessons learned from the Northridge earthquake. In large part, these lessons have been abstracted from a series of interim reports that were prepared in response to an executive order from the Governor of California. The senior author was responsible for the preparation of reports on natural gas and water supply. Tom Roche of EQE International prepared the material on electric power system performance. To put the performance of lifelines into perspective, a short section on general lifeline issues is presented.

3.2.1 General Lifeline Issues

Lifeline systems are generally considered to be an integral part of a community's infrastructure network. They provide the means and conveyance for daily as well as critical services and products. When these systems are damaged or rendered inoperable during a disaster, the livelihood and recovery of a region and community are directly affected.

Table 1. Lifeline Performance During The January 17, 1994 Northridge Earthquake

Lifeline	Population W/O Service	Restoration Time	Damage ($Million)
LADWP (Power)	100%	90% in 1 day	136
SoCal Edison	25%	99.9% in 1 day	0.5
LADWP (Water)	15%	8 days	44
MWD	-	-	5
LA City (Sewer)	-	-	36
SoCal Gas	3%	12 days	60
PacBell	8 communities	-	26
GTE	1%	-	3.5
CALTRANS	-	-	1,450
Total Damage			1,761

Lifeline systems have been shown to be particularly vulnerable to seismic effects. Because they possess special characteristics (both in terms of physical construction and operation), they are in many ways more vulnerable than buildings or other single-site facilities. Some of the features that make lifelines unique are:

- Lifelines cover large geographic areas.

  Because lifelines cover large areas, they are susceptible to a wide range of earthquake hazards. It is possible for different parts of a lifeline system to experience different levels of earthquake intensity or ground failure in the same event. It also is likely that some part of the system will be damaged or affected in large earthquakes that occur within the service region of the lifeline. For these reasons, earthquake hazard mitigation efforts must be based on an assessment of regional hazards and effects.

- Many lifelines are buried underground.

  The fact that many lifelines exist below ground imposes several unique problems in earthquakes. First, it is very difficult, and sometimes impossible, to immediately detect damage that has occurred underground after an earthquake. Systems that utilize pipelines under pressure are more likely to exhibit signs of damage or impact. On the other hand, post-earthquake damage to sewer systems, which are generally not pressurized, is very difficult to detect. Further, because many lifeline elements are located below ground, they are susceptible to permanent ground failure hazards. These hazards can cause serious damage to underground pipelines when deformations are larger than a few inches.

- Post-earthquake performance of lifelines is usually measured by degree of outage or serviceability.

  Unlike most buildings, where the predominant performance requirement is non-collapse, lifelines are required to provide important services after a major earthquake. Water is critical to fight post-earthquake fires; electric power service is necessary to insure the continued operation of critical and essential facilities (e.g., hospitals); communication systems are essential in coordinating post-earthquake response and recovery efforts. The design and construction of lifeline facilities must therefore consider acceptable post-earthquake performance criteria.

- Lifeline systems are owned, operated and regulated by a wide range of entities.

  Lifelines can be privately owned and operated, operated by municipal or government agencies, or operated as a utility district (that is, transcending some government boundaries). In California, the operation of privately-owned utilities are regulated by the California Public Utilities Commissions (CPUC). For municipally-owned utilities, such as the Los Angeles Department of Water and Power, the operation of the utility is overseen by government entities, such as City Councils. For utility districts, for example, the County Sanitation Districts of Los Angeles County, an elected Board of Directors will monitor the operation of the lifeline. The varied regulatory levels and reporting processes make it difficult to implement a coordinated statewide earthquake hazard mitigation program. The problem is further complicated when interstate lifeline systems, e.g., oil pipeline companies, are included.

  An additional problem relates to how these different lifeline agencies secure budgets for earthquake hazard mitigation programs. For the larger utilities, who generally fall under the responsibility of the CPUC, funding for such programs may come from special rate increases, or through long-term capital improvement programs. As long as the need for a particular program is effectively articulated, additional funding may be possible. For smaller utilities, many of which are municipally owned, funding is much more difficult to secure. For this reason, many smaller utilities have done little or none to mitigate earthquake hazards to their systems.

- Many lifeline systems are collocated.

  The routing of large transmission systems is governed by several factors. First, the topography of the region is a key factor. Lifelines in mountainous areas will generally follow narrow passes or valley areas. Second, the routing of lifelines may be restricted legally, i.e., utility corridors. Because of these factors, it is not uncommon to find several major lifelines collocated in the same corridor. In general, this is not a major problem. However, during earthquakes, this can result in serious impacts if one or more of these lifelines are damaged. For critical passes, such as Tejon or Cajon Passes in southern California, major disruption of lifeline services in these areas can mean major and long-term disruption of lifeline services for the region. In addition, damage from one lifeline system may result in indirect damage to an adjacent lifeline facility (e.g., leaking water undermining the support for adjacent lifelines, or gas explosions resulting in additional damage to surrounding lifelines). Recent studies have attempted to quantify these risks (Intech, 1991); follow-up studies are needed to identify possible mitigation measures.

All of the above factors underscore the need to assess the performance of lifelines in a manner different from that used for buildings. The significance of the lifeline issues resulting from the Northridge earthquake should be viewed with these factors in mind.

3.2.2 Lessons Learned

Lessons learned from the January 17, 1994 Northridge earthquake are listed for the following lifeline systems:

- Electric Power
- Water Supply
- Wastewater/Sewer
- Natural Gas
- Communication

3.2.2.1 Electric Power

Substation equipment displayed both positive and negative performances during the Northridge earthquake and was the primary reason for widespread power outages. The Northridge earthquake validated the ruggedness of many newer installations, such as 230Kv "dead tank" circuit breakers, yet, raised questions about the adequacy of several other designs. The poor performance of a substation due to a rigid bus configuration in lieu of flexible conductors and failures of relatively new disconnect switches were among the disappointments. Substations that were not modernized sustained damage to apparatus that were not expected to survive a moderate earthquake. High-voltage transformer bushings have surfaced as a weak link in upgraded substations. While isolated failures have been observed in past earthquakes, busing failures were much more prominent in this event and resulted in three transformer fires (Roche, 1994).

Important lessons also were learned regarding the performance of emergency power equipment. Electrical power is critical following an earthquake with virtually all aspects of emergency response and coordination dependent on normal, emergency or standby power generation. Numerous emergency and standby power systems were called into service following power outages related to the Northridge earthquake; however, many systems did not perform their intended functions.

Major mechanical equipment, such as engines, turbines, generators, fuel tanks and boilers did not sustain significant damage during the Northridge earthquake. Engineered electrical equipment such as transformers, motor control centers, switchgear and batteries generally functioned as desired with isolated failures reported. Cooling system damage resulted in several system failures. Most failures were not related to major system components; but instead were due to system logic, interfaces and operational anomalies.

Some of the problems encountered were not necessarily related to the earthquake. Instances of overheating generators and inoperable transfer switches for connecting loads to emergency services observed during the Northridge earthquake are similar to problems encountered during the 1977 New York blackout (U.S. Congress, Office of Technology Assessment, 1990).

Electric power systems are designed with redundancies such that the failure of single facilities or components will generally have a small impact on the overall system. Accordingly, the power system demonstrated resiliency during the restoration following the Northridge earthquake.

An apparent anomaly occurred along the Ventura plain where, although damage was minor, several hundred thousand people lost power for 12 hours. The area has ample generating capacity for the population; however, a single substation that is located much closer to the epicenter ties the region to the remainder of the power grid. Earthquake damage to circuit breakers, towers and other apparatus at the substation; coupled with maintenance outages at two of the Ventura plain power plants and minor damage at a third unit; left the region isolated from the power grid for 12 hours.

Backup power systems at generating stations also can facilitate power system restoration. Many plants require electrical power from the power grid to operate auxiliary systems and equipment for startup. A few plants have black-start capability, thus, can start without drawing energy from the local power grid. Additional plants equipped with black-start capability may improve power grid restoration following future earthquakes. Gas turbines, typically utility peak-load units and independent power producer cogeneration plants, are conducive to black-start service since they require minimal power to start and can achieve full load within minutes, compared to hours for steam plants.

3.2.2.2 Water Supply

The failure of major water transmission pipelines can have a significant short- and long-term impact on the response or recovery of a region. In the Northridge earthquake, five major water lines were disrupted. Fortunately, water could still be provided to the Los Angeles area from the Colorado River, groundwater basins, and local storage reservoirs.

In a larger earthquake, particularly one that occurs on the southern segment of the San Andreas fault, all major aqueducts into the Los Angeles region might be directly impacted (Dames & Moore, 1989), thus cutting off all imported water supply into the region. If this were to occur, existing water supply on the southern side of the San Andreas fault would not be sufficient to meet the region's emergency needs (Dames & Moore, 1989).

Since the major aqueducts are so vital to the region, some investigation should be made into the true vulnerability of these large-diameter transmission pipelines. In particular, special attention should be given to welded-steel pipelines with lap-welded joints. These joints are common within the transmission system, and have always demonstrated problems during large or moderate earthquakes. Investigations should focus on possible retrofit measures and new design details involving large-diameter welded steel pipe.

Current legislation requires that all California water delivery agencies with over 10,000 connections prepare and maintain an ongoing emergency preparedness program. As part of this program, it is anticipated that some seismic assessment of key elements would be required. It seems critical that in order to maintain a certain performance level, seismic standards should be in place for all critical water system components. At the present time, there are no required standards or codes in effect for water system elements, including water storage tanks.

There are several model standards from which water utilities can adopt to insure acceptable seismic performance. The American Water Works Association (AWWA) provides seismic design guidelines for steel (AWWA D100) and concrete (AWWA D110) water storage tanks. These standards can be reviewed and perhaps mandated for adoption by public water agencies under the SB1841 program. Adoption of such a standard would insure the seismic integrity of one of the most important components within the water system. The focus of these programs should be on providing flexibility in piping connections and insuring adequate strength in tank walls--the two most observed damage to water tanks by strong earthquake shaking.

It may be impossible for each water utility to completely design against the effects of a major earthquake. In these cases, contingency plans should be created that will insure compatibility with neighboring water utilities to maintain some level of minimum safety coverage. To some extent, this type of planning is already in place with mutual aid programs. Emergency coverage to areas that have lost water supply is provided by connecting these damaged systems to adjoining water systems operated by other cities or municipalities, or by using emergency fire pumpers to pump water between fire hydrants.

In order to insure that these systems are compatible, it is essential that all fire hydrants and apparatus connections are similar. Implementation of SB 1841 would insure that this requirement is met. The California Utilities Emergency Association could also be used as a vehicle for implementing this program.

3.2.2.3 Waste/Sewer

The wastewater collection system for the City of Los Angeles consists of a complex network of underground sewers, both gravity driven and forced mains. In total, over 7,000 miles of sewer pipe traverse the City of Los Angeles.

As in past earthquakes, damage to underground sewer pipes has been difficult to detect because the effects are not immediately visible, unless ground failure has occurred. In some cases, leaks and breaks are only detected when adjacent water mains are filled and wastewater spills onto the ground and street because of blockages caused by internal damage or collapse. Other indicators of severe sewer damage include street settlement, crushed or buckled curbs, damage to sidewalks and failed water mains.

In an attempt to more quickly identify areas of severe sewer damage, the city of Los Angeles proceeded with a two-step process (Solorzano et al., 1994). First, a geographical information system (GIS) was used by the Bureau of Engineering to identify areas of extensive building damage, water main repair and surface disruption (i.e., damage to sidewalks, roads, etc.). This information then was overlaid onto maps of the sewer system in order to prioritize close circuit television (CCTV) surveys. Areas that fell within relative high risk areas (e.g., areas with extensive building damage) were surveyed first. This assessment showed that approximately 16% of the inspected sewers needed emergency repair, 49% sustained damage that may require repair, and the remaining 35% sustained no damage. The total estimate of the replacement cost of the damaged sewer system has reached $36,000,000 (5 months after the earthquake). This total is expected to increase as inspections continue throughout the year.

3.2.2.4 Natural Gas

The failure of these older pipes appears to be limited to areas experiencing significant ground deformation (e.g., Balboa Blvd.) or areas experiencing very strong levels of ground shaking (e.g., line 1001 in Portrero Canyon). The Northridge experience substantiates earlier data indicating that these types of pipes within the SoCal Gas system are prone to earthquake damage. SoCal Gas recognized these vulnerabilities before the Northridge earthquake as shown by a 1986 report in which SoCal Gas investigated the feasibility of replacing seismically vulnerable pipelines in their system (Strang, 1986). As a result of this investigation, a large-scale pipe replacement program was started which addressed these steel transmission lines. The program to date has concentrated on areas of potential ground failure, including surface fault rupture, liquefaction and landslide. Because the failures observed along line 1001 have been attributed, in part, to traveling-wave effects (O'Rourke and Palmer, 1994), an additional consideration should be whether the pipe replacement program should also include areas of potential strong ground shaking (i.e., Modified Mercalli Intensity VIII or higher; see Table 2 for description of Modified Mercalli Intensity scale.)

A second issue arises when we recognize that the Balboa Blvd. area was not previously identified as an area of high ground failure potential (Tinsley et al., 1985). Significant ground failure was observed in this area during the Northridge earthquake. The seismological and geotechnical communities have yet to agree on the cause of these ground failures. Current beliefs include the possibility that secondary fault ruptures associated with this earthquake were responsible for ground failures at this site. Other possibilities include lurching (which is generally acknowledged to be caused by very strong ground shaking levels) or lateral spread (a type of landslide effect.) Because identification of potential ground failure areas is an important first step in assessing the seismic vulnerability of underground pipelines, current seismic hazard mapping programs should be expanded to include detailed assessments of these hazards.

According to SoCal Gas reports, natural gas-induced fires other than street fires were caused by: (1) damaged structures that fell off their foundations, and (2) failure of natural gas appliances. As seen in previous earthquakes, natural gas piping on the customer side of service connections (i.e., service connection, meter sets) are vulnerable to breakage when a structure falls off its foundation. Structures that are particularly vulnerable include single-family or multi-family dwellings located on cripple-stud foundations, and improperly braced mobile homes. In these situations, when the structure shifts off its foundation, it collapses onto or shears off the attached piping. If escaping gas is not shut off, this can lead to fire. According to SoCal Gas reports, there were approximately 172 mobile homes destroyed in the earthquake because of fires caused by natural gas leaks.

A second cause of natural gas fires is the failure of customer appliances. The most vulnerable appliance, from the standpoint of earthquake damage, is the water heater. According to SoCal Gas reports, approximately 2500 water heaters were damaged in this earthquake. Of the 47 fires that were attributed to natural gas-related structural fires, 35 to 40 percent were due to water heater failures (SoCal Gas, 1994)

3.2.2.5 Communication

As in recent events, the primary problem with communication facilities appears to be overload of operating systems. During the Northridge earthquake, the number of call attempts into the affected areas was about 225% over normal. The number of completed calls amounted to approximately 154 million, which represents a two times normal rate (PacBell, 1994). Some of the important lessons that were reported by PacBell (1994) are listed below:

1. A three-hour battery reserve is not sufficient in congested metropolitan areas, particularly at critical central offices.

2. Some critical central offices and most non-critical offices lack auto start/auto transfer for emergency engines.

3. Cable horns at some central office locations were considered to be the cause of some fires after the earthquake.

4. Reserve power routines (full and partial load engine runs) would have identified some of the problems experienced by emergency power generators.

Table 2. Modified Mercalli Intensity Scale
(excerpt, abridged)

I - V	Not significant to structures.
VI	Felt by all; many are frightened. Some heavy furniture moves; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Damage negligible to buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Chimneys, factory stacks, columns, monuments and walls fall. Heavy furniture overturned. Disturbs persons driving motorcars.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed. along with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

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4.0 ABOUT THE PANEL CHAIRS, VICE CHAIRS, SPEAKERS, AND NIST STAFF

DONALD BALLANTYNE, Associate, Dames & Moore. He earned his B.S. degree from Rensselaer Polytechnic Institute, and his M.S. degree in Civil Engineering from State University of New York at Buffalo. Don is a specialist on earthquake effects on lifeline systems. He has conducted detailed earthquake loss estimation studies and vulnerability assessments on over 25 water and wastewater systems including those serving Vancouver B.C.; Seattle, WA; Portland, OR; San Francisco, CA; Los Angeles, CA; Salt Lake City, UT. Current municipal clients include the Portland Bureau of Environmental Services, OR and the Marin Municipal Water District, Corte Maders, CA. Don also has performed projects for a number of government agencies, e.g., NIST, FEMA. He is currently studying the application of monitoring and control systems for mitigation of earthquake effects on lifelines with funding from NCEER.

Don has participated in the earthquake reconnaissance following events in Loma Prieta, the Philippines, Costa Rica, Turkey, and Northridge. He is the immediate Past Chair of the Technical Council on Lifeline Earthquake Engineering, ASCE. He was the editor for several books/chapters on various aspects of earthquake effects on lifelines. The American Water Works Association published his book, *Minimizing Earthquake Damage, a Guide for Water Utilities*.

FRANK W. BORDEN, Assistant Chief, Los Angeles City Fire Department Training Division. He has a B.S. degree in human relations and organizational behavior and has done graduate work at Loyola Marymount University, in addition to the National Fire Academy Executive Fire Officer Program and obtaining a State of California Teaching Credential.

Frank directs activities to prepare the Department, community and government to cope with the impact of disasters through training, education, research and development. He has held special assignments including development of the Department's Disaster Preparedness Program and Exercise Coordinator, Designer and Director of the City of Los Angeles Community Emergency Response Team Program; Operations Team member for the FIRESCOPE Program; Incident Command System Developer and Instructor; Investigation Team Leader for Coalinga, Mexico City, Whittler, Loma Prieta, 1994 Northridge, and 1995 Kobe Earthquakes; and involvement in local, State, national and international preparedness with Japan, Mexico, Colombia, Costa Rica, Canada, New Zealand, Germany, and the Central and Eastern European nations including Russia.

Several of Frank's professional affiliations include Chair of the California State Office of Emergency Services US&R Advisory Committee; Executive Board Member National Institute for Urban Search and Rescue; Vice Chair FEMA (Federal Emergency Management Agency) National US&R Advisory Committee. He also is a member of the International Association of Fire Chiefs Integrated Emergency Management System National Steering Committee and the National Fire Service Incident Management Consortium.

RILEY M. CHUNG, Leader, Earthquake Engineering Group, Structures Division, Building and Fire Research Laboratory, National Institute of Standards and Technology. He earned his B.S. degree from the National Taiwan University, an M.S. degree from Rensselaer Polytechnic Institute, and a Ph.D. from Northwestern University in Civil (Geotechnical and Earthquake) Engineering. Riley is a member of ASCE, EERI, WERC, and ISSMFE and a board member of International Design of the Extreme Environment Association.

Riley is responsible for the planning, management, coordination, and execution of NIST's earthquake engineering activities in problem-focused engineering research and in technology transfer under the National Earthquake Hazards Reduction Program (NEHRP).

Riley served at the National Academy of Sciences/National Research Council as Director, Division of Natural Hazard Mitigation, and earlier as a joint appointment, Director, Board on Geotechnology. He was responsible for the Academies' activities addressing issues in all types of natural hazards including the NEHRP program and also issues related to geotechnical engineering. He was responsible for a number of important studies including soil liquefaction, earthquake engineering for concrete dams, report to Congress on earthquake engineering research. He has been involved in organizing the coordinating post-disaster reconnaissance studies in many recent major natural disasters including the 1985 Mexico City Earthquake, the 1988 Spitak Earthquake in Armenia and, the 1989 Loma Prieta Earthquake. He also played a key role in establishing the 1990s International Decade for Natural Disaster Reduction (IDNDR), as so proclaimed by the United Nations.

RONNY J. COLEMAN, California State Fire Marshal. The State Fire Marshal is responsible for enforcing fire-related laws, investigating arson fires, providing training and education for all fire service personnel, approving fire alarm systems, and gathering statistical data on fires and burns occurring in the State. He received an A.A. degree in fire science from Rancho Santiago College, a B.A. in political science from the California State University at Fullerton, and a M.A. in vocational education from the California State University at Long Beach.

Ronny has been a lecturer in fire service training and education for over 25 years and is the author of nine fire service textbooks. He has served as the Fire Chief for the City of Fullerton, Fire Chief for the City of San Clemente, Operations Chief for the Costa Mesa Fire Department, and worked for the United States Park Service in Fire Protection.

Ronny currently serves as Chair of the National Fire Service Accreditation Committee and is Past President of the International Association of Fire Chiefs. He also is Vice President of the International Technical Committee for the Prevention and Extinction of Fire, a global fire service organization that represents approximately 40 nations.

Amongst his many prestigious honors and awards, Ron was selected as the "Fire Chief of the Year" by We-TIP, the "Outstanding Public Administrator Award" by the American Society of Public Administrators, and the "meritorious Recognition Award" by Operation Life Safety. He is a member of Omicron Tau Theta, a vocational education honorary society.

RONALD T. EGUCHI, Vice President, EQE International. He has directed major research and application studies in risk analysis, earthquake engineering and natural hazards engineering for government agencies (e.g., National Science Foundation, National Center for Earthquake Engineering Research) and major western and central United States utilities.

Ron is currently serving on a special California Seismic Safety Commission Panel that is preparing a report on the January 17, 1994 Northridge earthquake in response to Executive Order W-78-94. He is advising the Commission on issues related to the performance of lifeline systems in the Northridge earthquake. In addition, he is the principal investigator on a California Office of Emergency Services contract to collect and analyze earthquake damage resulting from the Northridge earthquake. He is a member of the Mayor's Blue Ribbon Panel for the City of Los Angeles that is developing an Earthquake Hazard Mitigation Program for the City. He presented an invited paper at the joint EERI/SA Symposium on the Effects of a Hypothetical Earthquake Beneath the City of Los Angeles.

Ron participated in a special White House workshop to assess a National Earthquake Strategy for the United States. He has authored over 100 publications in this area, many of them dealing with seismic risk of utility lifeline systems. Amongst his activities, he is past chair of the Executive Committee of the ASCE Technical Council on Lifeline Earthquake Engineering, past member of the Editorial Board of the EERI technical journal *SPECTRA*, past chair of a joint FEMA/NIST steering committee that prepared a plan for the development of seismic design standards for all public and private lifelines, and is currently a member of the Research Committee of the NCEER.

RUSSELL P. FLEMING, Vice President of Engineering, National Fire Sprinkler Association. He has B.S. and M.S. degrees in civil engineering from Rensselaer Polytechnic Institute. Russ is a leading fire protection engineer with an international reputation as an expert in water-based fire suppression systems. He also serves as an Adjunct Assistant Professor in the graduate program in fire protection engineering program at Worcester Polytechnic Institute, where he has been developing a text in water-based fire suppression systems.

Russ is the editor of the bimonthly technical newsletter he initiated for the sprinkler industry, Sprinkler *TechNotes*. He developed and continues to produce an international newsletter entitled International *SprinklerScene*. He also has authored a number of books and articles, including *Quick Response Sprinklers - A Technical Analysis*.

Russ is active in the National Fire Protection Association, serving on a number of technical committees including the Committee on Automatic Sprinklers and the Committee on Water Mist Systems. He chairs the NFPA 13 task group on Design Approaches and for the past ten years also chaired the task group on Earthquake Protection. He serves as chair of the NFPA Standards Council, which oversees all standards-writing efforts of that organization. He also has served as a member of the Mechanical - Electrical System Subcommittee of the Building Seismic Safety Council. He is a member of the National Society of Professional Engineers and is a past president of the New York Chapter of the Society of Fire Protection Engineers. From 1978 through 1990 he served as Chief Delegate for the United States in international standards activities relating to sprinkler and water spray equipment, leading to the adoption of the first international sprinkler product standard in 1991.

DONALD O. MANNING, Chief Engineer and General Manager, Los Angeles City Fire Department. Born, raised and educated in Los Angeles, he entered the United States Air Force and served during the Korean War. He was appointed to the Los Angeles City Fire Department in 1955 and gained national prominence as the manager of two test programs that played a significant role in reducing fire-related fatalities: The California Fire Chiefs' Association's Smoke Detector Test Program; The U.S. Fire Administration's Residential Sprinkler Test Program.

Don has focused on developing the "full service" concept in emergency services. Some examples of the things that the LA City Fire Department has accomplished are: Disaster Preparedness Division was organized to educate and train the community to provide for their own needs immediately following a major disaster, over 400,000 civilians have been exposed to the program, and fire sprinklered retrofit for high-rise buildings and older multi-storied habitational occupancies.

Some of Don's professional affiliations include Governor's California Emergency Council; Emergency Operations Board, City of Los Angeles; International Association of Fire Chiefs. Among his many awards, some are Executive of the Year, 1983; Southern California's Top 100 Executives, 1986; Fire Prevention Award of Excellence, 1986.

BIJAN MOHRAZ, Professor, Mechanical Engineering, Southern Methodist University in Dallas, and currently a visiting scholar in the Structures Division of the National Institute of Standards and Technology's Building and Fire Research Laboratory. He earned his B.S., M.S., and Ph.D. in civil engineering from the University of Illinois at Urbana-Champaign. He is a Fellow of the American Society of Civil Engineers, a member of the Earthquake Engineering Research Institute, the Structural Engineers Association of Texas, and has served as a member and chair of several technical committees of the ASCE Structural Division. A consultant to government and private industry, he now is a member of the Board of Directors of the Applied Technology Council, a nonprofit California organization engaged in applied research in earthquake engineering. He is the editor of ASCE *Journal of Architectural Engineering* and is a registered professional engineer in the State of Texas.

Bijan's area of research is earthquake engineering and structural dynamics, and he is the author and co-author of over sixty publications including a chapter on Ground Motion and Response Spectra in the *Seismic Design Handbook* published by Van Nostrand-Reinhold.

His professional experience includes serving as Research and Project Engineer with Agbabian-Jacobsen Associates in Los Angeles and on the civil engineering faculty at the University of

Illinois before joining SMU where he later served as the Associate Dean of the School of Engineering and Applied Science and as the Chair of Civil and Mechanical Engineering.

FREDERICK W. MOWRER, Associate Professor, Department of Fire Protection Engineering, University of Maryland. He received his Ph.D. in Fire Protection Engineering and Combustion Science from the University of California at Berkeley. He currently serves on the Board of Directors of the Society of Fire Protection Engineers and as the Past President of the Research Section of the National Fire Protection Association. He is a registered fire protection engineer in the State of California.

Fred teaches graduate and undergraduate courses on hydraulics, automatic fire detection and suppression system design, fire testing, fire modeling and causative analysis of fires. He conducts research on a range of fire-related topics, including the reaction of materials to fire, fire detection, fire suppression and has developed methods of quantitative fire hazard analysis for use in nuclear power plants and in atria and other large spaces.

Currently, Fred is on sabbatical at the National Institute of Standards and Technology, where he is working with the Large Fire Research Group of the Building and Fire Research Laboratory. He is investigating transmission paths for exterior fires to penetrate building envelopes to become interior fires, with emphasis on windows as a potential pathway. This has implications for wildland-urban interface fires, post-earthquake fires and other structural conflagrations.

THOMAS D. O'ROURKE, Professor, Civil Engineering, Cornell University. He also has been a member of the teaching and research staff at the University of Illinois at Urbana-Champaign. His teaching has covered many aspects of geotechnical engineering, including foundations, earth-retaining structures, and slope stability. He received his B.S. degree from Cornell University, a M.S. and a Ph.D. from the University of Illinois at Urbana-Champaign.

Tom has been involved with problems concerning foundation performance, ground movement effects on structures, earth-retaining structures, pipelines, and earthquake engineering both on a research and consulting basis. He has developed techniques for estimating ground movement patterns for a variety of excavations, tunneling, and mining conditions. He has formulated methods for evaluating tunnel boring machine performance. He has developed analytical methods and existing strategies to mitigate pipeline damage during earthquakes, and has established full-scale testing facilities for buried pipelines.

Tom is a member of the national Academy of Engineering. He is a member of the ASCE, ASME, ASTM, AAAS, ISSMFE, EERI, UTRC, and IAEG. Amongst his other activities, he is a past chair of the UTRC Technical Committee on Tunnel Lining Design, UTRC Executive Committee, the ASCE Earth Retaining Structures Committee. He is a member of the NCEEP Research Committee and EERI Learning from Earthquakes Committee.

WILLIAM J. PATTERSON, Manager, Fire and HAZMAT Programs, Federal Emergency Management Agency, Region 9. He also assists state and Indian communities in the assessment of hazards and development of emergency plans and implemented training for hazardous materials incidents. He attended the Long Beach City College, California State University at Long Beach, University of Southern California, and the United States Fire Academy. Recently he has participated as a member of American Fire Service group sharing safety technical information with many foreign governments including Japan, China, Korea, England, Europe, the former Soviet Union, South American, Australia and New Zealand.

Bill's work experience spans some 50 years and includes planning, managing, and coordinating activities and programs associated with public safety. He has served as a teacher in several colleges and has published a number of fire safety and hazardous materials related articles.

He is a member of the California Joint Legislative Committee on Fire, Police, and Emergency and Disaster Services. He is a past member of the International Association of Fire Chiefs, HAZMAT Committee, and past Chair of the California Fire Chief's Association of HAZMAT Committee, and the Western Fire Chiefs Association HAZMAT Committee. He is a member of the Hazardous Materials Regional Response Committee of both Oceania and Federal Region IX. He also has a State of California Life Time Teaching Credential and is a registered Fire Protection Engineer in the State of California.

WILLIAM DOUGLAS WALTON, Acting Leader, Large Fire Research Group, Fire Safety Engineering Division, Building and Fire Research Laboratory, National Institute of Standards and Technology. He is responsible for laboratory and mesoscale experiments to investigate the burning of weathered and emulsified crude oils on water and develops engineering methods for analysis of large fire events, e.g., wildland/urban and post-earthquake fires. He received a B.S. degree in Fire Protection Engineering and a M.S. in Mechanical Engineering from the University of Maryland.

Doug developed the techniques for the measurement of heat release rate and flame spread, ASET-B (the first personal computer-based compartment fire model), and the evaluation of sprinkler response and effectiveness. He developed the concept of using a computer bulletin board to disseminate computer fire models. He has been a facilities fire protection engineer for the Central Intelligence Agency and has over 15 years firefighting experience.

Doug has served as a part-time lecturer in the Department of Fire Protection Engineering at the University of Maryland. He has taught courses in computer-aided analysis of sprinkler and water distribution systems, heat transfer, computer fire modeling, and fire test instrumentation. He has co-authored chapters in the NFPA *Fire Protection Handbook* and the *SFPE Handbook of Fire Protection Engineering*. He also is a section editor for the *SFPE Handbook of Fire Protection Engineering*. Doug is a Fellow in the Society of Fire Protection Engineers and a registered professional engineer in the State of Delaware.

5.0 ACKNOWLEDGMENTS

Special thanks are extended to Charles Scawthorn (EQE Engineering) and Frank Borden (L.A. City Fire Department) for their timely (literally hours after he returned to the United States) slide presentation and discussion on the Kobe earthquake. The special efforts of the Panel Chairs: Russ Fleming (National Fire Sprinkler Association), Ronny J. Coleman (California State Fire Marshal), and Ron Eguchi (EQE Engineering); the Vice Panel Chairs: Tom O'Rourke (Cornell University), Don Ballantyne (Dames and Moore), Bill Patterson (Federal Emergency Management Agency), are cited for keeping the participants focussed on the task at hand. The efforts of Jack E. Snell, H. S. Lew, and David D. Evans (NIST) are noted for assisting in the development of the agenda, and identifying speakers and attendees. Special thanks go to Betty Thames (NIST) for providing excellent secretarial and receptionist support before, during, and after the workshop.

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A post-earthquake fire and lifeline workshop sponsored by the Building and Fire Research Laboratory, National Institute of Standards and Technology, was held January 30-31, 1995, in Long Beach, California. The objective of the workshop was to identify technology development and research needs that will be used in developing recommendations to reduce the number and severity of post-earthquake fires. The workshop participants included leaders in the fire service, fire protection engineering, codes and standards, insurance, transportation systems, and water, gas, power distribution, and telecommunication utilities systems with experience in dealing with consequences of earthquakes. The workshop participants developed a list of priority project areas where further research, technology development, or information collection and dissemination would serve as a vital step in the future reduction of the losses from post-earthquake fires.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)
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