- Sewers: As a result of loss of power and damage to pump station buildings and equipment, sewage (in reduced volumes because of water system dysfunction) would overflow from manholes into city streets, back up into basements, and run into drainage conduits. Sewers in areas that suffer significant permanent ground deformation would be destroyed completely. Sewers in less-affected areas might sustain damage that would go unnoticed, presenting a hazard to health.

- Sewage treatment plants: In an earthquake, sewage treatment plants not designed for seismic resistance would sustain damage. Raw or inadequately treated sewage that had reached the sewage treatment plant would be discharged into the receiving water body.

Providing water for fire suppression is the most critical requirement for water system function following an earthquake. The city of San Francisco was largely destroyed by fire after the 1906 San Francisco earthquake because the water system was inoperable. Following the 1906 earthquake, the city constructed an earthquake-resistant auxiliary water system to provide water for fire suppression for the next earthquake.

Neither the municipal nor the auxiliary water system was functional in some areas of San Francisco requiring water for fire suppression following the 1989 Loma Prieta earthquake. The city was extremely fortunate that there was no wind the evening of the earthquake to spread the fires that resulted.

2.3 CURRENT PRACTICES

2.3.1 Electric Power Systems

Buildings associated with power systems generally are subject to local building codes. This includes power plants, the structures that contain plant energy control centers, substation control houses, service center buildings, and buildings for the technical support staff. Within California, building codes have included seismic requirements for some time and are constantly being updated. However, older structures may be deficient. Outside California, most building codes have not had seismic requirements--a situation that only now is beginning to change. Building codes establish minimum criteria for life safety. Lifeline experts believe that severe damage can be expected in a major earthquake and that buildings necessary for continued power system operation may not be functional.

In general, most power system facilities other than buildings are not governed by seismic codes or standards. An exception is the Western Area Power Administration's substations. WAPA uses Institute of Electrical and Electronic Engineers (IEEE) Standard 693, *Recommended Practice for the Seismic Design of Substations*, a standard that otherwise is seldom used. Large power utilities have manuals of practice that cover the design and construction of power facilities; outside California, however, most utilities have few if any seismic requirements. Many utilities have formally adopted a 0.2g horizontal static force requirement for substation equipment, which if used in procurement specifications is typically not considered seriously. The use of this requirement for equipment anchorage, particularly for critical high-voltage substation equipment, is very limited.

In general, California utilities have instituted practices to improve seismic performance. For most utilities outside California, earthquake hazard is not considered a salient issue, and little has been done to improve the seismic response of their facilities. One exception is the Bonneville Power Administration (BPA) in the Northwest, which since the 1971 San Fernando earthquake has completed a comprehensive seismic study; initiated a seismic upgrade program; and established policy, criteria, and standards for new and existing systems [7].

The Technical Council on Lifeline Earthquake Engineering of ASCE has conducted a series of specialty conferences and symposia addressing seismic issues related to power systems. Proceedings have been published. TCLEE has also published *Advisory Notes on Lifeline Earthquake Engineering*. This material is descriptive in character and is not in a standard or code format. These notes review earthquake damage and give some general guidance for improving the seismic response of power systems. Detailed suggestions are given for the anchorage of a few types of equipment.

2.3.2 Gas and Liquid Fuel Systems

The minimum standards for gas and liquid fuel systems are defined in Title 49 of the Code of Federal Regulations (CFR), Parts 192 and 195, respectively [8,9]. The federal regulations for transportation of gas and liquids are based, respectively, on American National Standards Institute (ANSI) B31.8 and B31.4, which have been developed and maintained by technical committees of the American Society of Mechanical Engineers (ASME). Except for a general statement of the need to design liquid pipelines (ANSI B31.4 and 49 CFR 195) for the effects of earthquake-induced external loads, the ANSI standards and the CFR do not prescribe seismic design requirements. These standards and regulations represent minimum requirements for design, construction, and operation; many companies exceed the requirements stipulated by the ANSI standards and the CFR for safety.

A guideline on the seismic design of most major components of oil and gas pipeline systems was prepared by the ASCE Committee on Gas and Liquid Fuel Lifelines in the early 1980s [10]. The document was intended primarily for engineers engaged in the design of oil and gas pipelines and facilities; however, it also provides guidance to pipeline company management, regulatory groups, disaster recovery agencies, and insurance companies. The document is a compendium of knowledge on the practice of earthquake engineering for oil and gas pipeline systems but is not a design manual, code, or standard.

Most new pipeline systems, especially those in regions of high seismic exposure, are now subject to the requirements of federal and state governmental regulatory agencies for design to mitigate geologic hazards. The Federal Energy Regulatory Commission (FERC) and the Department of the Interior regulate interstate natural gas and oil transmission systems, respectively, while state public utility commissions regulate intrastate pipelines. There is no regulation or guiding policy for prescribing seismic mitigation measures; rather, it seems that seismic issues are addressed more or less independently for each project.

Current practice for the seismic design of major pipeline systems (new construction) follows the precedent set by the nuclear industry in that two levels of earthquake hazard are selected for design. The low-level event generally has a return period of 50 to 100 years and is referred to as the probable design earthquake (PDE). As a requirement self-imposed by the owner, the system is designed to withstand the PDE without significant damage and with minimal interruption of operational functions. The higher-level event is generally one that has a return period of 200 to 500 years or more, depending upon the nature of the facility. This event is referred to as the contingency design earthquake (CDE) and is an event for which the major regulatory requirement is that the system not pose a threat to safety or to the environment, although significant structural damage could occur. The amount of permissible damage varies according to the type of structure or component and its function.

Except for American Petroleum Institute (API) Standard 650 for liquid storage tanks and various standards and regulations for liquid natural gas tanks (e.g., 49 CFR 193 [11]), no codes or standards are directly applicable to the seismic design of gas and liquid fuel systems. The 1984 ASCE guidelines partially fill this void by providing a comprehensive and perceptive summary of accepted practice.

Since the publication of the ASCE guidelines, a number of studies have advanced the knowledge of seismic hazard mitigation for gas and liquid fuel systems.

At most plant facilities, structural design has been performed in accordance with governing building codes. Since 1988, the Uniform Building Code (UBC) has been generally applicable to industrial facilities. Lifeline experts believe that the code lacks specific guidance, however, in the classification of structures and components according to performance objectives and relative importance.

2.3.3 Telecommunication Systems

There are no uniform practices across the range of telecommunication companies, although there are some remnants of the historic Bell System practices in most of the central offices. Furthermore, private networks have practices that are different from those of the public networks. Telecommunication systems have evolved so quickly after divestiture that it is difficult to track what has changed.

Since the industry is no longer regulated, competition dominates most planning and investment decisions. There are no standards governing all telecommunication systems. Although a competent level of engineering to mitigate earthquake damage is feasible and achievable, the lack of demand and requirement has kept the industry from reaching that level.

For equipment protection in switching facilities, planners and purchasing agents are specifying seismic protection as a requirement. Bellcore and ATC specifications are used for this purpose. New products are required by the Bell Operating Companies to meet seismic requirements specified in the Network Equipment Building System specifications. However, non-Bell companies are not following this practice.

Public Switched Network facilities in general do not use central fire suppression systems, but materials used in these facilities have to meet Underwriters Laboratories (UL) specifications. When Public Switched Network facilities share a building with other tenants, however, the fire suppression system is required to meet codes. Lifeline experts believe that damage caused by these systems may be far more extensive than that caused by the fire itself.

Regarding transport facilities, the Bell Operating Companies follow Bellcore specifications (TRTSY-000043, Above-Ground Electronic Equipment Enclosures, and TRTSY-000026, Below-Ground Electronic Equipment Enclosures). Much of this information originated from Bell

System practices. These specifications do not address earthquake-related design and installation practices, however, and there is a knowledge gap in certain areas, such as fiber-optic cable.

It is common practice to leave cable slack between splice points or between poles. Though not driven by seismic considerations, this practice reduces the possibility of excessive strain on the cable due to ground movements.

2.3.4 Transportation Systems

Very few standards have been written explicitly for the design and construction of transportation lifelines. Those that do exist are only for components (e.g., bridges), and none addresses system wide performance.

Current practice is therefore based on sound professional judgment, which means that where relevant codes or standards are available they are used; where they are absent, design guidelines are based on judgment. This judgment may, in turn, be based on previous experience in the same field or borrowed from similar experience in related fields (e.g., building design).

Of all the transportation components, the highway bridge has been the most closely studied for seismic vulnerability, and standards have been prepared for bridge seismic design.

The best example of such a standard is the seismic specification for new highway bridges, adopted by the American Association of State Highway and Transportation Officials in 1990. These AASHTO requirements are philosophically defensible and nationally applicable. Some states, such as California, have developed their own seismic specifications for bridges, which take into account regional differences in seismicity and design practice.

On the other hand, standards for upgrading existing highway bridges are not as well developed. A set of retrofit guidelines was issued by FHWA in 1983, and the California Department of Transportation (CalTrans) has prepared in-house material for its bridge engineers, but there is no standard or universal guide for the seismic retrofitting of existing bridges at this time.

The same is true for other common modes of transportation, such as railroads and rapid-transit systems. Nationally accepted seismic design requirements do not exist for these systems, and hence considerable differences are found in seismic design requirements and practice. However, general recommendations for bridges are included in Chapters 8 and 15, for concrete and steel railroad structures, respectively, of the current American Railway Engineering Association (AREA) *Manual for Railway Engineering*, but these are not considered to be as rigorous as the AASHTO highway bridge requirements.

In the absence of a unified code, current design practice for mass-transit systems in seismic areas appears to use a selection of codes and standards drawn from various sources.

The situation for the other transportation lifelines appears to be similar. There are no codes or standards written specifically for these systems.

2.3.5 Water and Sewer Systems

Current design and construction practices have been documented by ASCE's TCLEE, primarily through the use of a guideline approach. Guidelines and/or standards of practice have been specifically developed for water and sewer systems by the U.S. military, the Japan Society of Civil Engineers, a municipal utility, and a consultant. These documents are in varying levels of detail, incorporate an inconsistent list of considerations, and do not have consensus among a wide range of users in the United States. While the first of these, the Tri-Service Manual, was not developed specifically for water and sewage facilities, it may have the most complete coverage available for such facilities. This document considers some policy, system evaluation, and component design. It includes relevant chapters on mechanical and electrical elements; structures other than buildings, including elevated tanks, vertical tanks, horizontal tanks, and buried structures; and utility systems, including earthquake considerations for utility systems, general and specific planning considerations, and design considerations. Design details are also included.

Equipment and materials standards that consider seismic design exist in some categories for tanks, pipe, plant piping, and electrical equipment.

- Tanks: The American Water Works Association (AWWA) has standards for steel (AWWA D100-84), bolted steel (AWWA D103-87), and prestressed concrete tanks (AWWA D110-86). Each of these three standards has specific requirements for seismic-resistant design of these three categories of tanks.

- Buried pipe: The AWWA has standards for ductile iron, steel, concrete, and asbestos cement pipe; fittings; valves; and hydrants. It also has standards for pipe installation. While these standards address such things as materials controlling ductility and bell dimensions controlling spigot insertion length and allowable rotation, there is no specific reference to seismic design.

- Plant piping: Several professional and manufacturers' organizations have standards and guidelines for plant piping. ASME Pressure Vessel and Piping Code 31.1 includes detailed requirements for design of pipe/support structural systems. The code is used in the energy and manufacturing industries. The National Fire Protection Association (NFPA) standard for installation of fire sprinklers includes seismic-resistant pipe-support details [12]. This standard is usually applied only to sprinkler systems, although it is a good reference for other types of pipe-support detailing. The Manufacturers Standardization Society has three standards (MSS 58, 69, and 89) governing different aspects of pipe supports, none of which considers seismic design [13-15].

- Electrical equipment: IEEE has a standard for seismic qualification of equipment for the nuclear industry [16]. This standard is not applied in the water and sewage industry because of the extreme additional cost of the equipment. The National Electrical Manufacturers Association (NEMA) has no provisions for seismic resistance in its full spectrum of electrical equipment specifications normally applied in water and sewage facility designs.

- Wells: Current well design standards do not include seismic considerations.

2.4 REFERENCES

1. *Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States*, ATC 25, Applied Technology Council, 1991.

2. Eguchi, Ronald T., and Susan D. Pelmulder, "Impact on the National Energy Distribution Network," *Indirect Economic Consequences of a Catastrophic Earthquake*, Development Technologies, Inc., Washington, DC, October 18, 1991.

3. *Earthquake Loss Estimation for the City of Everett, Washington's Lifelines*, prepared by Kennedy/Jenks/Chilton for USGS, May 1991.

4. *Estimated Future Earthquake Losses for St. Louis City and County, Missouri*, Earthquake Hazards Reduction Series 53, FEMA/Central United States Earthquake Preparedness Project, June 1990.

5. Ebel, John, E. Fratto, K. Kadinsky-Cade, N. Remmer, E. Thomas, M. N. Toksoz, and K. Wiesner, *Metropolitan Boston Area Loss Study, Loss Analysis Committee Report and Recommendations*, Massachusetts Civil Defense Agency, February 1990.

6. *An Assessment of Casualties for Six Cities in the Central United States Resulting from Earthquakes in the New Madrid Seismic Zone*, FEMA/Central United States Earthquake Preparedness Project, October 1985.

7. *Procedures and Criteria for Increasing the Earthquake Resistance Level of Electrical Substations and Special Installations*, R-7211-13-2859, prepared by Agbabian and Associates for the Bonneville Power Administration, September 30, 1973.

8. "Transportation of Natural and Other Gas by Pipeline," Title 49, *Code of Federal Regulations* (CFR), Part 192, U.S. Department of Transportation, 1991.

9. "Transportation of Hazardous Liquids by Pipeline," Title 49, *Code of Federal Regulations* (CFR), Part 195, U.S. Department of Transportation, 1991.

10. *Guidelines for the Seismic Design of Oil and Gas Pipeline Systems*, American Society of Civil Engineers, 1984.

11. "Liquefied Natural Gas Facilities: Federal Safety Standards," Title 49, *Code of Federal Regulations* (CFR), Part 193, U.S. Department of Transportation, 1991.

12. *Installation of Sprinkler Systems*, NFPA 13, National Fire Protection Association, 1989.

13. *Pipe Hangers and Supports—Materials, Design, and Manufacture*, ANSI/MSS SP-58, Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 1975.

14. *Pipe Hangers and Supports—Selection and Application*, ANSI/MSS SP-69, Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 1976.

15. *Pipe Hangers and Supports—Fabrication and Installation Practices*, MSS SP-89, Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 1978.

16. *Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations*, IEEE Standard 344-1987, Institute of Electrical and Electronic Engineers.

Table 2.1

DIRECT-DAMAGE LOSSES TO REGIONAL NETWORK LIFELINES
($ millions)

Scenario Earthquake	Highways	Electric Power	Railroads	Natural Gas	Refined Oil	Crude Oil	Water
Cape Ann	382	1312	9	0	0	0	0
Charleston	773	1264	156	0	0	0	0
Fort Tejon	470	886	158	11	0	28	140
Hayward	206	1310	115	6	0	0	91
New Madrid (M = 8.0)	2216	2786	458	56	28	47	0
New Madrid (M = 7.0)	204	1077	106	19	9	19	0
Puget Sound	496	1834	96	6	0	0	18
Wasatch Front	323	90	31	6	0	0	0

Data from References 2.4.1 - 4.

Table 2.2

DIRECT DAMAGE LOSSES TO
LOCAL DISTRIBUTION SYSTEMS
($ billions)

Scenario Earthquake	Electric Power	Water	Highways
Cape Ann	0.89	0.30	0.60
Charleston	0.74	0.31	0.50
Fort Tejon	0.91	0.23	0.23
Hayward	0.90	0.20	0.25
New Madrid (M = 8.0)	2.07	0.88	1.40
New Madrid (M = 7.0)	0.65	0.28	0.44
Puget Sound	0.58	0.09	0.28
Wasatch Front	0.38	0.13	0.26

Data from References 2.4.1 - 4.

Table 2.3

INDIRECT ECONOMIC LOSSES

Scenario Earthquake	Indirect Loss (in billions, 1991 $)
Cape Ann	9.1
Charleston	10.2
Fort Tejon	11.7
Hayward	11.1
New Madrid (M = 8.0)	14.6
New Madrid (M = 7.0)	4.9
Puget Sound	6.1
Wasatch Front	3.9

Data obtained by summing Table 2.1 and 2.2

CHAPTER 3: PRIVATE AND PUBLIC SECTOR ROLES IN THE DEVELOPMENT OF DESIGN GUIDELINES AND STANDARDS

3.1 RESPONSIBILITIES FOR SEISMIC SAFETY OF LIFELINES

The nation's lifeline infrastructure encompasses thousands of individual facilities that are owned, operated, and regulated in distinctly different ways to fill critical national needs. The lifeline infrastructure reflects the diversity inherent in providing the various services (electric power, gas and liquid fuel, telecommunications, transportation, water and sewer) [1]. Discussed below are the responsibilities for the performance of lifeline facilities, including their seismic safety, which extend across many public and private sector interests —owners, operators, regulators (local, state, federal), manufacturers, suppliers, design professionals, and contractors.

The development, adoption, and application of effective seismic design guidelines and standards for existing and new lifelines are the major means through which future earthquake damage could be reduced. Information on how a cooperative program will be managed and coordinated to accomplish the goal is presented and discussed in Chapter 4.

The various owners, operators, and regulators of lifelines (private and public) are vitally concerned with the efficacy, efficiency, and economy of design guidelines and standards that govern the seismic performance of lifelines. They must be directly involved in the development of recommendations for such guidelines and standards if they are to understand them, have confidence in their quality, and implement them effectively.

Other groups as well—manufacturers, suppliers, design professionals, researchers, contractors, trade associations, technical and professional societies—should be directly involved. In the case of manufacturers and suppliers of equipment and services, design guidelines and standards will affect the properties required of, and the market for, their products and services. Design professionals have principal responsibilities for correctly interpreting and applying guidelines and standards in the evaluation of and retrofitting of existing lifelines and in the design of new ones. Researchers must be involved because their experience and expertise will be valuable to the development process. General and specialty contractors are responsible for correctly implementing project specifications in retrofitting and constructing lifelines. Trade associations and technical and professional societies aggregate the interests of owners, operators, manufacturers, and suppliers and provide efficient means for their interests to be represented in the development process and in implementation.

3.1.1 Owners and Operators

Most electric power, gas and liquid fuel, telecommunication, and railroad facilities are privately owned and operated, as are many water supply systems. State highways, bridges, and tunnels and federal-aid highways are owned by individual states. Local governments own municipal, county, and parish roads, bridges, and tunnels. They and regional authorities own and operate water and sewer, light rail/transit, airports, and ports and harbors. In the midst of these facilities, and sometimes interconnected with them, are federally owned lifelines. Federal facilities represent a small percentage of the total number of lifeline facilities.

Ownership influences how the application of mitigation measures for the retrofitting of existing facilities or for new facilities can be effected. Theoretically, government-owned systems (e.g., highways and bridges) should be more readily updated and protected because they are operated in the public interest; however, fiscal considerations often impede this process, as has been the case with bridges and highways that require upgrading and replacement. Also, it would be reasonable to expect that investor-owned utilities (e.g., telephone, pipeline, and certain electric power systems) would update their facilities to maintain their corporate reputation for safety and reliability, to protect themselves from liability claims by victims of lifeline failure, and to protect their capital investments. In actuality, this happens only if the utility perceives its facilities to be sufficiently at risk, and if mitigation is feasible [1].

3.1.2 State and Local Regulators

Electric power, gas, telecommunication, and railroad utilities typically are regulated by state public utility commissions. State highway and transportation departments administer highways, bridges, and tunnels. Municipalities, counties, and parishes generally operate and maintain their highways, bridges, and tunnels through local public works departments. Those local governments or authorities established to own and operate region-wide water and sewer, light rail/transit, airport, and port and harbor facilities tend to be self-regulators; that is, states often delegate authority to them to regulate their own operations. Many state and local activities are similar to those described below for federal regulators.

3.1.3 Federal Regulators

The existing framework of federal regulation of lifelines includes:

- Direct federal ownership and operation of lifelines
- Financing and grants-in-aid
- Licensing, permitting, and rate making
- Disaster assistance

Systems owned and operated by the federal government include the Department of Energy's Western Area Power Administration, Bonneville Power Administration, and Southwestern Power Administration (transmission systems) and Alaska Power Administration (a generation and transmission system). The federal government also owns and operates the Tennessee Valley Authority and, under the Department of Transportation, the Federal Highway Administration (which designs and constructs roads and bridges within federal lands) and the Federal Aviation Administration (which constructs, owns, leases, or operates staffed and unstaffed facilities to support the National Airspace System). Through the Bonneville Power Administration, Southeastern Power Administration, Alaska Power Administration, and Southwestern Power Administration, the Department of Energy sells as well as transmits power.

The federal government provides financing and grants-in-aid through the Department of Transportation's Federal Highway Administration, which funds the Federal-Aid Highway Program, the Highway Bridge Replacement and Rehabilitation Program, and emergency repair and reconstruction. DOT's Urban Mass Transportation Administration makes matching grants to finance construction and rehabilitation of public transit systems, and its Federal Aviation Administration funds airport planning and development programs.

The government's function in licensing, permitting, and rate making for lifelines is fulfilled by a number of federal bodies. The Department of Energy's Federal Energy Regulatory Commission sets rates and charges to transport and sell natural gas, transmit and sell electricity, and transport oil by pipeline. It also licenses hydroelectric projects. The Federal Communications Commission regulates interstate and foreign communications by wire and radio, including radio and television broadcasting; telephone, telegraph, and cable television operation; two-way radio and radio operation; and satellite communication. And the Interstate Commerce Commission regulates interstate surface transportation, including railroads, and certifies carriers, rates charged, and adequacy of service. In a related role, the federal government creates safety regulations through the Department of Transportation. DOT's Office of Pipeline Safety regulates natural gas and hazardous liquid pipeline safety standards programs, including a program through which states can assert safety regulatory jurisdiction. Also through DOT, the Federal Railroad Administration regulates rail safety, including track maintenance, inspection standards, equipment standards, and operating practices, and inspects railroad and related industry equipment, facilities, and records. And through the Environmental Protection Agency, federal regulators administer programs for water supply and water pollution control and ground-water protection, as well as other programs not related to seismic design for lifelines.

The federal government provides disaster assistance through several agencies. The Federal Emergency Management Agency (FEMA) coordinates these activities. Additionally, FEMA administers federal disaster assistance programs for presidentially declared disasters, including funds to repair, restore, reconstruct, or replace public and private nonprofit facilities owned by state or local governments.

3.2 NEHRP SUPPORT FOR THE DEVELOPMENT OF RECOMMENDATIONS FOR LIFELINE SEISMIC DESIGN GUIDELINES AND STANDARDS

When the risks of and vulnerability to damage from earthquakes from all areas of the country are added together, the federal government has more potential exposure than any other single unit of government or organization. No other governmental body or private entity has as much incentive to foster consistent standards on a national basis. If the various lifeline areas were to move wholly by voluntary consensus, without the catalytic encouragement and financial assistance of the federal government, the process would take decades and the results would be uneven.

In keeping with the objectives of the National Earthquake Hazards Reduction Program, it is recommended that federal responsibilities for the development and adoption of seismic design guidelines and standards for lifelines be carried out under NEHRP. The approach and responsibilities of the NEHRP Lead Agency and NIST for carrying out the Lifeline Seismic Standards Program are discussed in Chapter 4.

3.3 REFERENCES

1. *Strategies and Approaches for Implementing a Comprehensive Program to Mitigate the Risk to Lifelines from Earthquakes and Other Natural Hazards*, prepared by the Ad Hoc Panel on Lifelines, National Institute of Building Sciences, for FEMA, June 1989.

CHAPTER 4: THE DEVELOPMENT OF DESIGN GUIDELINES AND STANDARDS

4.1 THE PROCESS OF DEVELOPING DESIGN GUIDELINES AND STANDARDS

Design guidelines lay out a set of principles, which for lifelines may include performance criteria, materials characteristics, and testing procedures for design, construction, maintenance, repair, and retrofitting of both existing and proposed systems. Guidelines provide a basis for making judgments or determining a course of action; they may evolve into recommendations for standards. The definition of a standard provided by the National Standards Policy Advisory Committee is "a prescribed set of rules, conditions, or requirements concerning definitions of terms; classification of components; specification of materials, performance, or operation; delineation of procedures; or measurement of quantity and quality in describing materials, products, systems, services, or practices" [1]. In terms of building design and construction, a standard may be a specific set of requirements or instructions for the testing, design, manufacture, installation, and use of a building material component or system [2]. Standards for lifeline design and construction must give special attention to the performance of each lifeline as a system and to the interdependence of the various lifeline systems.

The primary public benefits of standards are the improvement of safety and the safeguarding of health and welfare. A standard exists when an agreement has been obtained on its content. The level of agreement may range from a consensus of employees of an organization (company standard) to a full consensus developed by representatives of all sectors that have an interest in the use of the standard (consensus standard). Consensus standards generally receive the highest level of recognition by regulators and others involved in design and construction because of the rigorous procedural requirements and broad participation in the process. Once a consensus standard is approved, it usually is maintained and updated periodically.

In general, the promulgation of a consensus standard is preceded by a variety of research, testing, and prestandard development activities. Under certain appropriate conditions, guidelines and standards may be developed at a faster pace through an iterative process. It begins with a set of preliminary guidelines, applied and assessed in demonstration projects through which technical knowledge gaps can be identified; needed problem-focused research can then be carried out to fill those gaps. In other words, demonstration projects provide the opportunity to improve the original set of guidelines that later will be developed into a standard.

4.2 THE RECOMMENDED APPROACH

A cost-effective approach that will result in near-term implementation activities to reduce the current vulnerability of existing lifelines and simultaneously minimize the limitations that may exist in financial and human resources is being recommended.

The approach takes into consideration limitations on resources; acknowledges particular features of lifelines that may have greater impact on loss of life, property damage, and economic consequences; and establishes a system of prioritization. It focuses initially on the highest-priority types of lifeline systems, on the performance of existing lifeline systems, and on the early realization of benefits to the public through prototype demonstration projects.

Development activities would begin with several of these demonstration projects, each involving a specific lifeline system, using draft guidelines developed with the existing knowledge base. Each would involve vulnerability assessments for a range of earthquake scenarios, the development of prioritized lists of possible actions to upgrade the system, the evaluation of performance improvement and cost, and the formulation of an action plan, in conjunction with the owners and regulators. It is envisioned that there will be two rounds of prototype demonstration projects (possibly overlapping). Experience from the first round will form the basis for guidelines—in effect, the first version of prestandards—for the conduct of such projects.

This approach would evolve prestandards—and thence standards—while at the same time providing valuable ongoing examples of significant hazard reduction efforts. The assessment of available knowledge and the identification and performance of problem-focused research and development would proceed concurrently with the prototype demonstration projects—with cross-feeding concerning research needs and results.

The approach has built-in flexibility, which results from the use of guidelines and standards prepared from current knowledge, the trial application of those guidelines and standards, and their successive improvement as experience with application increases.

4.3 POLICY STATEMENT/STRATEGY

As stated, the basic strategy for this approach is to evolve prestandards through demonstration projects involving the upgrading of existing lifelines. Lessons learned from the retrofitting of existing lifelines can be applied as well to the development of design guidelines and standards for new systems. It is recognized that this approach may not initially use consistent performance requirements for the various lifeline systems, but the evolving prestandards will be monitored, and efforts will be directed toward achieving as much consistency as possible.

The work plans for the initial demonstration projects will be based on existing technology and knowledge, through which the draft guidelines can be prepared. Critical problem-focused research needs will be identified at the outset through assessment of current knowledge and also will emerge in the course of the earliest projects. Results from such research will be applied to the later projects and in the writing of prestandards.

Planning for and management of the initial projects will be provided by a group of people experienced in lifeline earthquake engineering. At this stage it is not essential for this group to include representatives of all standards-writing organizations, although the knowledgeable people may come from some of these groups. However, all interested parties will be kept informed during this early phase of the project. As the time for developing actual prestandards approaches, it will be necessary to bring the standards-writing organizations into the project in a more formal way.

4.4 MANAGEMENT

Strong leadership is needed for a project as diverse and complex as this one. The successful execution of the Plan will require very careful and skillful management and coordination. It is envisioned that management will involve the NEHRP Lead Agency, NIST, and a group of private and public sector experts for lifeline seismic design guidelines and prestandards studies, who will later interact with representatives of existing national standards-setting organizations and professional organizations.

4.4.1 The Roles of the NEHRP Lead Agency and NIST

The NEHRP Lead Agency, in coordination with NIST, will provide oversight of the Plan's development and implementation. The NEHRP Lead Agency's mechanisms for providing grants and technical assistance to the states and the private sector will support the implementation of standards.

Subsequent to a decision to activate this Plan, The NEHRP Lead Agency, in coordination with NIST, will create an ad hoc working group for the purposes of nominating and selecting the chair and members of the Board of Directors of a body that will be known as the Lifeline Seismic Safety Executive Board, and of nominating and selecting the director and staff of the Executive Directorate. Upon completion of these tasks, the working group will be dissolved.

NIST, principal agency of NEHRP for research and development for improving building codes and standards and practices for structures and lifelines, will provide subsequent program management and technical support for implementing the plan.

Close liaison will be maintained with the fundamental research programs of the National Science Foundation and the U.S. Geological Survey that are conducted under NEHRP. Research needs will be identified for NSF and USGS, and research results will be applied in the development of lifeline seismic design guidelines and standards.

4.4.2 The Lifeline Seismic Safety Executive Board

The development and adoption of lifeline seismic design guidelines and standards will be carried out in two stages. The work in the first stage will be accomplished through the Lifeline Seismic Safety Executive Board (hereafter referred to as the Board). The second stage will require sustained private sector standardization activities, which must be carried out by the existing national standards groups and professional organizations, with assistance from the Board.

The Board will be made up of three components: the Board of Directors, the Lifeline Directorates, and the Executive Directorate.

The Board of Directors will consist of a chair, from the private sector, a representative of ICSSC and 12 to 15 technical experts recommended by major lifeline organizations. These organizations may include the Institute of Electrical and Electronic Engineers, the American Petroleum Institute, Bellcore, the American Association of State Highway and Transportation Officials, the American Society of Civil Engineers, and the American Water Works Association. The membership of the Board of Directors must provide a balance between researchers and practitioners. The Board of Directors will define and address the needs and issues of all five lifeline systems to develop a prioritized overall program plan, including the selection of demonstration projects.

The activities commissioned by the Board of Directors will be carried out by one of the Lifeline Directorates (hereafter referred to as the Directorates). A separate Directorate will be established for each of the five lifeline systems. The Directorates will address the specific issues and concerns in each lifeline category as well as conduct specific technical studies of relevance to various lifelines—for example, the development of risk-based vulnerability analysis models. Each Directorate may have six to ten experts, selected by the Board of Directors. For each lifeline system, a Directorate will review and synthesize existing research and existing guidelines and standards to develop draft guidelines for that lifeline system. These guidelines will be assessed in demonstration projects and refined by the Directorates at the completion of these projects. Not all the Directorates need be established at the outset of the Board's process. Only those lifeline types for which demonstration projects are selected will need their corresponding Directorates in place to support and facilitate prestandards development.

The Executive Directorate will include a full-time director and staff selected by the *ad hoc* working group created by the NEHRP Lead Agency and NIST to form the LSSEB. This Directorate, supported by NIST, is to provide management and administrative support to the Board of Directors and the Lifeline Directorates.

The Board of Directors will establish a cooperative agreement with the Interagency Committee on Seismic Safety in Construction. ICSSC is the mechanism by which federal agencies affected by NEHRP can collaborate in the establishment of earthquake hazard reduction practices. Currently 31 agencies involved with the construction or use of buildings and lifelines participate in ICSSC. The interests of these agencies and their technical expertise are represented on ICSSC through its Subcommittee on Lifelines. This subcommittee has participated in the studies leading to this Plan. The agreement, as a minimum, defines areas of common interest, establishes a subcommittee responsible for guiding joint activities, and appoints an ICSSC member to serve on each of the Lifeline Directorates.

4.5 COORDINATION OF PRIVATE SECTOR STANDARDIZATION ACTIVITIES

Each of the lifeline types has existing regulatory, standards, and specifications organizations that represent the interests of the owners and the public served. Each also includes representation or input from the technical community, designers, suppliers, operators, and the public. Improvements in seismic design and construction practices and standards for existing and proposed lifeline systems will be most effectively implemented through these organizations. Some of these organizations have not yet been concerned with earthquake performance issues, however, and need to use expertise from the earthquake hazard mitigation community.

Lifelines are public works and utility systems owned and/or regulated by the private sector and local, state, and federal governments. All of these have fundamental interests in protecting lifeline systems from earthquakes. Because the federal government has more lifeline systems exposed to potentially damaging earthquakes than any other single organization has, the successful adoption and implementation of design and construction guidelines and standards for lifelines requires close coordination between federal agencies and nonfederal organizations, including local and state governments.

4.5.1 The Board's Long-Term Responsibilities

The Board may play a critical role in facilitating and coordinating development and implementation activities, interacting with the private standards-setting bodies and professional organizations. The Board is to offer knowledge and ideas, policy and technical expertise, and a forum for establishing broad representation and guidance in the development of standards for seismic safety in the planning, design, construction, retrofitting, and operation of lifeline systems.

The Board's major functions and responsibilities in this regard will be as follows:

- To support the development and adoption of national voluntary consensus guidelines and standards

- To serve as an independent and authoritative focal point, working with the existing standards groups and professional organizations to ensure the development of private design guidelines and standards for lifelines

- To encourage lifeline industries and associated manufacturers, associations, and professionals to consider earthquakes and their impacts in the planning, design, construction, and operation of lifeline systems

- To develop recommendations, including priorities, for lifeline seismic safety guidelines and standards development, research, and implementation activities, including prototype demonstration projects

- To conduct annual workshops to present progress reports and raise project-related issues and to encourage and obtain input from the industries and associated manufacturers' associations, standards groups, NEHRP, ICSSC, and professional organizations

- To submit annually a written report to the NEHRP Lead Agency, through NIST, on the progress and status of the project.

4.5.2 ICSSC's Role

The authority for the establishment of ICSSC is pursuant to provisions of the National Earthquake Hazards Reduction Act of 1977 and its amendments thereafter, and Executive Order 12381. ICSSC helps the federal departments and agencies involved in construction to develop and incorporate earthquake hazard reduction measures in their ongoing programs. These measures will be based on existing standards when feasible and will be consistent with OMB guidelines giving preference to the use of appropriate private sector, national consensus standards. ICSSC also cooperates with state and local governments and private sector organizations in developing nationally applicable earthquake hazard reduction measures. It can become a vital link in the implementation of these measures through its individual agencies. ICSSC will be represented on each Lifeline Directorate, per the cooperative agreement discussed above, to help promote federal use of standards promulgated by the lifeline standards organizations and to obtain consistency in federal and private sector uses of the recommendations for lifeline standards.

4.6 WORK PLAN

The process for developing and adopting seismic design guidelines and standards for lifelines begins with the establishment of the Board and its Executive Directorate to perform their respective functions described herein. With input from the lifeline community and federal agencies, the Board and the Executive Directorate will select the Directorates' members and demonstration projects.

Demonstration projects are a key element in this recommended approach. They provide opportunities to show early success of the program. They also allow a concentrated effort, early on, on the performance of existing lifeline systems. Thus, priorities in the development of guidelines will be guided by the potential for demonstration projects.

The strategy is to learn from demonstration projects. There have already been a few such projects in California, such as those of Pacific Gas and Electric Company. These pilot projects have demonstrated that much can be accomplished by replacing key equipment as part of regular maintenance cycles, and that equipment manufacturers already have made available more seismically resistant equipment at relatively little increase in cost.

This approach will begin by categorizing lifelines both by nature and by size in order to select some for inclusion as early demonstration projects. For example, FHWA is already addressing seismic standards for new and existing highway systems. Telecommunication facilities may be dealt with in cooperation with private companies and concerned federal agencies. Ports/harbors and airports may be best addressed jointly with port and airport authorities. A comprehensive list of lifeline systems might include the following examples:

- Large utilities in California (perhaps the need is only to encourage them in what they are already doing and to be sure to learn from their efforts)

- Small utilities in California

- Large utilities in areas of moderate seismic hazard: Puget Sound, New Madrid, etc.
- Small utilities in areas of moderate seismic hazard
- Large federal utilities (e.g., TVA)
- Small federal utilities, such as those connected with military facilities

From such a list, the Board would choose three to four instances, depending on the availability of funds. The selection should be carried out in consideration of priorities for reducing earthquake hazards and for federal, state, and local government and industry collaboration. When appropriate, federally owned utilities may be selected as demonstration projects.

These projects should be undertaken by full-time experts drawn from the Directorates, in collaboration with engineering organizations experienced in such projects and with consultants as appropriate. Collaboration in each demonstration project will be obtained from the affected industries and/or organizations before the projects proceed. Each project should include establishing the seismic hazard for several levels of probability; estimating the fragility of the various links and components; analyzing the implications of failure of the weakest links and components; developing a prioritized list for replacement and upgrading, including schedule and costs; and interacting with regulatory bodies and perhaps the public.

Draft guidelines should be prepared at the beginning of each of the demonstration projects. The result of each project will be an updated version, which should at that stage already be of potential practical use and which would become the starting point for subsequent projects and the prestandard—the starting point for standardization. Lessons learned from the conduct of these demonstration projects will help shorten the time needed for the development of standards for proposed lifeline systems.

It is anticipated that in the early years of the project, the Board will be focusing on the development of prestandards and demonstration projects; in the latter years, it will be focusing on working with standards groups and professional organizations on the development and adoption of guidelines and standards. It is anticipated that at the end of the project, the Board and its Directorates will cease to exist unless it is deemed necessary that the Board or an element of the Board be maintained for continued updates and consensus.

4.7 IMPLEMENTATION

Education and implementation efforts should begin immediately when some lifeline prestandards are developed and ready for adoption by standards organizations through a consensus process. This is one of the most important tasks that the Board will tackle. Potential users will be involved early in the design guidelines and standards development process. Education and training must be part of the implementation process.

After the development of voluntary consensus lifeline seismic standards, NEHRP will promote the implementation of such standards "by Federal, state, and local governments, national standards and model building code organizations, architects and engineers, and others with a role in planning and constructing buildings and lifelines" [3]. With private sector, local, and state government participation in developing recommendations for design guidelines and standards (as well as their participation in voluntary consensus standards committees) and in educational programs for their use, it is expected that adoption and implementation of lifeline seismic standards will be expedited.

Federal voluntary use of the standards will follow OMB Circular A-119 (October 26, 1982), which states that it is the policy of the federal government in its procurement and regulatory activities to:

> [6.]a. Rely on voluntary standards, both domestic and international, wherever feasible and consistent with law and regulation pursuant to law; . . .

Circular A-119 states that voluntary standards that are consistent with applicable laws and regulations should be adopted and used by federal agencies unless the agencies are specifically prohibited by law from using them, and should be given preference over nonmandatory government standards unless the use of such voluntary standards would adversely affect performance or cost or have other significant disadvantages. Preference should be given to those standards based on performance criteria when such criteria may reasonably be used instead of design, material, or construction criteria. Agencies should not be inhibited, if within their statutory authorities, from developing and using government standards in the event that voluntary standards bodies cannot or do not develop a needed, acceptable standard in a timely fashion.

To expedite implementation by federal agencies, it is recommended that an executive order be drafted for the implementation of seismic design guidelines and standards for federal lifelines. An executive order might require federal agencies to use seismic guidelines and standards for federal and federally assisted or regulated existing and new lifelines and provide incentives for private sector and state and local government adoptions. Agencies involved would request funds through their respective budget request processes to carry out the executive order. However, a broadly applicable executive order will be infeasible before guidelines or standards are available for all types of federal lifelines.

As with Executive Order 12699, Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction, the ICSSC would have responsibility for recommending procedures for implementing the executive order pertaining to lifelines [4].

4.8 RESEARCH

As the work described above proceeds, needs for fundamental research will be identified in order to guide the efforts of NSF, NCEER, and USGS in the continued improvement of the knowledge base for seismic safety of the nation's lifelines.

4.9 INTEGRATION INTO THE INFRASTRUCTURE PROGRAM

Execution of the lifeline plan will be coordinated closely with the nation's infrastructure programs, both the ongoing ones and the ones that are planned for the future. For example, many federal agencies are currently planning for programs to revitalize the nation's infrastructure systems. These include FHWA, which has initiated seismic standards development in its own programs for highways. NSF has organized a civil infrastructure research program through coordination among several divisions within NSF. All of these agencies are active in ICSSC, which can relate lifeline seismic standards efforts to other federal infrastructure activities.

4.10 FUNDING AND SCHEDULING

Funding to implement the Plan will be requested through separate budget requests by federal agencies with missions for support of research and development for lifeline guidelines and standards. For example, FHWA, working with NCEER and others, is already supporting studies for developing and adopting seismic design guidelines and standards for highway lifelines.

Funds are needed to support NIST's role to manage the activities to be carried out by the Board and to provide technical support for the implementation of the Plan. The majority of the funds, however, will be used for private sector work to conduct the engineering studies of the Board's Directorates and demonstration projects.

The level of funding request will vary depending on the stage of the project. Programmatic needs will be carefully reviewed annually, along with factors such as the support of full-time experts for each of the Directorates and the cost of conducting the demonstration projects, so that funding requests can be adjusted to develop lifeline seismic safety guidelines and standards expeditiously and efficiently.

The work by the Board and its Directorates is expected to take six to eight years to complete. However, for the more vulnerable lifeline systems identified and chosen as prototype demonstration projects, only four years should be required to complete the work. It is estimated that standards for all five lifeline types will be completed and adopted for use in eight to ten years, through a well-coordinated effort including a comprehensive and aggressive education and training program.

4.11 REFERENCES

1. Breitenberg, Maureen A., *The ABC's of Standards-Related Activities in the United States*, NBSIR 87-3576, National Bureau of Standards, May 1987.

2. Dikkers, Robert D., "Standards—Tools for Excellence," *Corrections Today*, American Correctional Association, April 1987.

3. Section 5, Public Law 95-124, Earthquake Hazards Reduction Act of 1977, as amended.

4. Todd, D., and Ann Bieniawski, *Guidelines and Procedures for Implementation of the Executive Order on Seismic Safety of New Building Construction*, NISTIR-4852/ICSSC RP-2.1A, National Institute of Standards and Technology, June 1992.

APPENDIX: CONTRIBUTORS TO THE PLAN

1. COORDINATING MEMBERS

Mr. Ronald T. Eguchi
EQE Engineering and Design
18101 Von Karman Ave., Suite 400
Irvine, CA 92715

Mr. Harold W. Andress, Jr.
FEMA
500 C Street SW
Washington, DC 20472

Mr. William S. Bivins
FEMA
500 C Street SW
Washington, DC 20472

Mr. Robert D. Dikkers
NIST
Building and Fire Research Laboratory
Gaithersburg, MD 20899

Mr. John Foss
Bell Communications Research
435 South Street, Room 1A334
Morristown, NJ 07960

Mr. James R. Hill
U.S. Department of Energy
Safety and Technology Division
Washington, DC 20585

Dr. George C. Lee
SUNY/Buffalo
412 Bonner Hall
Buffalo, NY 14260

Dr. H. S. Lew
NIST
Building and Fire Research Laboratory
Gaithersburg, MD 20899

Mr. R. Michael McCafferty
Western Area Power Administration
P.O. Box 3402
Golden, CO 80401

Mr. H. Crane Miller
3401 Lowell Street NW
Washington, DC 20016

Dr. Douglas J. Nyman
D. J. Nyman & Associates
12337 Jones Road, Suite 204
Houston, TX 77070

Dr. Masanobu Shinozuka
NCEER
SUNY/Buffalo
Red Jacket Quadrangle
Buffalo, NY 14261

Mr. James R. Smith
National Institute of Building Sciences
1201 L Street NW, Suite 400
Washington, DC 20005

2. NEHRP ADVISORY COMMITTEE

George K. Bernstein, Esq.
1730 K Street NW, Suite 313
Washington, DC 20006

Dr. Clarence R. Allen
Seismological Lab 252-21
California Institute of Technology
Pasadena, CA 91125

Dr. Richard Andrews
California Office of Emergency Services
2800 Meadowview
Sacramento, CA 95832

Mr. Christopher Arnold
Building Systems Development
3130 La Selva, Suite 308
San Mateo, CA 94403

Dr. James E. Beavers
Martin Marieta Energy Systems, Inc.
Building 9207, Mail Stop 8083
P.O. Box 2009
Oak Ridge, TN 37831-8083

Dr. Vitelmo V. Bertero
Civil Engineering Department
Earthquake Engineering Research Center
University of California
1301 South 46th Street
Richmond, CA 94804

Dr. John N. Davies
Geophysical Institute
University of Alaska
Fairbanks, AK 99775-0800

Ms. Evelyn Davis
Community Education Services
Children's Television Workshop
1 Lincoln Plaza, 4th Floor
New York, NY 10023

Mr. Gerald H. Jones
Codes Administration
City of Kansas City
18th Floor, City Hall
Kansas City, MO 64106

Mr. Paul Pomeroy
86 Abeel Street
Kingston, NY 12401

Mr. Roland L. Sharpe
Roland L. Sharpe Consulting
Structural Engineering
10051 Pasadena Avenue
Cupertino, CA 95014

Dr. Kathleen J. Tierney
Disaster Research Center
University of Delaware
77 East Main Street
Newark, DE 19716

Mr. L. Thomas Tobin
California Seismic Safety Commission
1900 K Street, #100
Sacramento, CA 95814

Dr. Robert Whitman
Department of Engineering
Massachusetts Institute of Technology
Room 1-342
Cambridge, MA 02139

3. PRELIMINARY LIFELINES ASSESSMENT

Electrical Power Lifelines

Dr. Anshel J. Schiff
Stanford University
27750 Edgerton Road
Los Altos Hills, CA 94022

Dr. James E. Beavers
Martin Marieta Energy Systems, Inc.
Building 9207, Mail Stop 8083
P.O. Box 2009
Oak Ridge, TN 37831-8083

Mr. Ben Damsky
Electric Power Research Institute
Safety & Technology Department
3412 Hillview Avenue
Palo Alto, CA 94304

Mr. Edward N. Matsuda
Pacific Gas and Electric Co.
Civil Engineering Dept., Rm. F 1504A
1 California Street
San Francisco, CA 94106

Mr. Dennis Ostrom
Southern California Edison Co.
2244 Walnut Grove Avenue
Rosemead, CA 91770

Mr. Ronald A. Tognazzini
Los Angeles Dept. of Water & Power
1890 Canyon Close Road
Pasadena, CA 91107

Gas and Liquid Fuel Lifelines

Dr. Douglas J. Nyman
D.J. Nyman & Associates
12337 Jones Road, Suite 204
Houston, TX 77070

Mr. Thomas L. Anderson
Fluor Daniel Inc.
3333 Michelson Drive
Mail Stop 533T
Irvine, CA 92730

Mr. Charles B. Crouse
Dames and Moore
500 Market Place Tower
2025 1st. Ave
Seattle, WA 98121

Dr. William Hall
University of Illinois
3105 Valley Brook Drive
Champaign, IL 61821

Mr. Peter W. McDonough
Mountain Fuel Supply Co.
180 E. 1st South
Salt Lake City, UT 84139

Dr. Thomas D. O'Rourke
Cornell University
265 Hollister Hall
Ithaca, NY 14853

Telecommunication Lifelines

Mr. Alex Tang
Northern Telecom Canada Ltd.
2591 Pollard Drive
Mississauge, Ontario
Canada, L5C 3G9

Mr. Ted J. Canon
H. J. Degenkolb Associates
350 Sansome Street, Suite 900
San Francisco, CA 94104

Mr. John Foss
Bell Communications Research
435 South Street, Room 1A334
Morristown, NJ 07960

Dr. Jeremy Isenberg
Weidlinger Associates, Inc.
4410 El Camino Real, Suite 110
Los Altos, CA 94022

Dr. S. Chi Liu
Program Director
National Science Foundation
4201 Wilson Blvd.
Arlington, VA 22230

Dr. Masanobu Shinozuka
NCEER
SUNY/Buffalo
Red Jacket Quadrangle
Buffalo, NY 14261

Mr. Lawrence F. Wong
Pacific Bell
2600 Camino Ramon, Room 3S800
San Ramon, CA 94583

Transportation Lifelines

Dr. Ian Buckle
NCEER
SUNY/Buffalo
Red Jacket Quadrangle
Buffalo, NY 14261

Mr. James D. Cooper
ICSSC
c/o Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101

Mr. James H. Gates
Caltrans Division of Structures
P.O. Box 942874
Sacramento, CA 94274

Dr. Geoffery R. Martin
Department of Civil Engineering
University of Southern California
3620 S. Vermont Ave., KAB, Rm. 210
Los Angeles, CA 90089

Dr. James E. Monsees
PB/MK Team
7220 South Westmoreland Rd., No. 200
Dallas, TX 75237

Dr. Stuart D. Werner
Dames & Moore
2101 Webster St., Suite 300
Oakland, CA 94612

Water and Sewer Lifelines

Mr. Donald B. Ballantyne
Kennedy/Jenks/Chilton
530 South 336th Street
Federal Way, WA 98003

Mr. Walter F. Anton
Seattle Water Department
Dexter Horton Bldg., 9th Floor
710 2nd Avenue
Seattle, WA 98104

Mr. Holly A. Cornell
CH2M Hill
2300 NW Walnut Blvd.
P.O. Box 428
Corvallis, OR 97339

Mr. William M. Elliott
Portland Water Department
2250 Park Road
Lake Oswego, OR 97034

Mr. Le Val Lund
3245 Lowry Road
Los Angeles, CA 90027

Dr. Michael O'Rourke
Rensselaer Polytechnic Institute
Troy, NY 12180-3590

Federal Roles in Development, Adoption, And Implementation of Seismic Design Standards for Lifelines

Mr. H. Crane Miller
3401 Lowell Street NW
Washington, DC 20016

Dr. Harold C. Cochrane
Department of Economics
Colorado State University
Ft. Collins, CO 80523

Dr. Joanne Nigg
Disaster Research Center
University of Delaware
Newark, DE 19716

Dr. William J. Petak
University of Southern California
Inst. of Safety & System Mgmt.
Los Angeles, CA 90089-0021

Mr. Robert A. Olson
VSP Associates, Inc.
455 University Avenue, Suite 340
Sacramento, CA 95825

Dr. Craig E. Taylor
Dames & Moore
911 Wilshire Place, Suite 700
Los Angeles, CA 90017

Other Contributors

Dr. T. Ariman
College of Engineering &
Applied Sciences
University of Tulsa
Tulsa, OK 74104-3189

Dr. Clifford Astill
National Science Foundation
4201 Wilson Blvd.
Arlington, VA 22230

Ms. Sandy Auchmoody
NIST
Building & Fire Research Laboratory
Gaithersburg, MD 20899

Mr. Robert J. Belecky
Public Service Company of Colorado
2701 West 7th Avenue
Denver, CO 80204

Lt. Col. Michael S. Cleary
National Communications System
Joint Secretariat (NCS-NJ)
701 South Courthouse Road
Arlington, VA 22204

Mr. Steven Dreyer
Pacific Gas and Electric Co.
123 Mission Street, Room H1002
San Francisco, CA 94106

Ms. Laurel Harrington
Seattle Water Department
Dexter Horton Bldg., 9th Floor
710 2nd Avenue
Seattle, WA 98104

Mr. Edwin Jones
American Society of Civil Engineers
345 East 47th Street
New York, NY 10017

Mr. Gerald J. Klaus
Public Service Company of Colorado
2701 West 7th Avenue
Denver, CO 80204

Mr. Jack D. McNorgan
Southern California Gas Co.
M.L. 730C, Box 3249
Los Angeles, CA 90051-1249

Mr. Joseph Pavlus
AMOCO Pipeline
One Mid-America Plaza, Suite 200
Oak Brook Terrace, IL 60181

Dr. William U. Savage
Pacific Gas and Electric Co.
215 Market Street, Room 760
San Francisco, CA 94106

Mr. Richard Shaw
International Safety Systems
16270 Raymer Street
Van Nuys, CA 91406

Mr. George O. Thomas
Department of Energy
Western Area Power Administration
P.O. Box 3402
Golden, CO 80401