(DRAFT)

A Plan to Coordinate NEHRP Post-Earthquake Investigations

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February 28, 2002

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1. Executive Summary

This is a plan to coordinate domestic and foreign post-earthquake investigations supported by the National Earthquake Hazards Reduction Program (NEHRP). The plan addresses coordination of both the NEHRP agencies – Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology (NIST), National Science Foundation (NSF), and U. S. Geological Survey (USGS) – and their partners. The plan describes how to coordinate what is going to be done. Coordination is addressed in various time frames ranging from hours to years after the earthquake. The plan includes measures for (1) gaining rapid and general agreement on high priority research opportunities, and (2) conducting the data gathering and field studies in a coordinated manner. It deals with identification, collection, processing, documentation, dissemination, and archiving of the results of the post-earthquake work and achieving these tasks in a timely manner and an easily accessible format and medium.

For the purposes of this plan a significant domestic earthquake is defined as either (a) an earthquake resulting in a Presidential disaster declaration, or (b) an earthquake considered by NEHRP agencies to provide an opportunity to learn how to reduce future earthquake losses in the United States. The plan organizes domestic post-earthquake investigation and information dissemination activities into three phases, which include the following elements:

Phase I (immediate to several days)

- *Incident Report and Plan Implementation:* Within a few minutes after a large or potentially damaging domestic earthquake, the USGS shall notify emergency managers, NEHRP agencies, state geological survey(s) in the affected state(s), and personnel designated by the NEHRP agencies. Following this incident report, the USGS shall consult with the NEHRP agencies, the state geological survey(s), and the Earthquake Engineering Research Institute (EERI) to determine if the earthquake is significant and warrants implementation of all or part of the NEHRP post-earthquake coordination plan.
- *Web Site Management:* Within hours of the event, the USGS shall establish an event Web site with links to other earthquake-related Web sites. The USGS shall have principal responsibility for collating and linking to earth-science information. EERI shall have principal responsibility for collating and linking to engineering information as provided by the engineering centers, institutions, and private practice.
- *Technical Clearinghouse:* Within 24 hours following mutual consultation, the USGS, FEMA, and EERI will work with state agencies to organize a field technical clearinghouse. Depending on ability and capability, the state may take the lead in organizing the clearinghouse. The clearinghouse is the focal point for coordinating activities of all field parties during initial post-earthquake reconnaissance.
- *NEHRP Investigations Coordinator:* Within 24 hours, the USGS in consultation with the other NEHRP agencies shall designate a NEHRP Investigations Coordinator. The Coordinator shall be kept abreast of all NEHRP activities and communications with regards to the earthquake, ensure liaison with emergency managers is adequate, and work with the NEHRP agencies to optimize the deployment of NEHRP resources and to establish priorities for investigations.

Phase II (several days to 1 month)

- *Meeting:* When the initial reconnaissance phase nears completion, the NEHRP Investigations Coordinator shall convene a meeting to identify opportunities and needs for rapid concentrated data gathering and investigation, including systematic collection of perishable data. Within 24 hours of the meeting, the Coordinator shall prepare a report containing summary reconnaissance findings, recommendations for collection of perishable data, and an estimate of both the level of effort and amount of funding that will be required to conduct recommended activities. On the basis of this report, NEHRP agencies will invite, consider, and support proposals for rapid investigations. The Coordinator shall be kept informed of all NEHRP-supported investigations in order to facilitate coordination and minimize duplication of effort.

Phase III (1 month to 5 years)

- *Workshop on Investigation Priorities:* Within one to two months of the earthquake, NSF and the USGS shall jointly sponsor a multidisciplinary workshop to evaluate long-term research and development opportunities. The workshop will identify major opportunities and recommend priorities for funding.
- *Investigations Solicitation*: Based on the Workshop on Investigation Priorities and within constraints of available funding, a joint statement shall be issued by FEMA, NIST, NSF, and the USGS that solicits long-term research, problem-focused studies, and statements of qualifications for research and problem-focused studies. If possible, awards are to be made within five months of the event.
- *Information Dissemination:* NEHRP shall support at a minimum three types of information dissemination activities following every significant domestic earthquake.
  - An *event summary* report for a broad audience shall be published within 3 months of the event. The report shall integrate preliminary observations on the response of the natural, built, and socioeconomic environments. It shall be prepared with the formal collaboration of EERI, the USGS, and other NEHRP supported investigators.
  - On the *first anniversary* of the earthquake, FEMA, NIST, NSF, and the USGS, shall support local and state agencies involved in risk reduction to hold a *public conference* with an accompanying proceedings that summarizes the implications of the earthquake and identifies opportunities for earthquake risk reduction. The conference and proceedings shall be targeted at local and state decisionmakers and shall be held in the region impacted by the earthquake.
  - A *comprehensive synthesis* of research and professional reports shall be published within five years of the event by the USGS and NIST. Data and other detailed information shall be archived in a NEHRP virtual data center and appropriately summarized in the synthesis report.

For foreign earthquakes, which typically are less intensively investigated than domestic earthquakes, the plan recommends that all U.S. post-earthquake investigators inform EERI of plans and schedules of investigations before departure as well as their ongoing status once in the field. EERI shall regularly report these planned activities and their status to the NEHRP

agencies. NEHRP agencies shall monitor these plans to avoid interference by U.S. visitors with local experts.

This proposed plan concludes with recommendations that address several deficiencies in current domestic post-earthquake investigations. The deficiencies were identified at an invitational workshop of experienced post-earthquake investigators held as part of the process to prepare this plan. Areas in need of major improvement include:

- Coverage and comprehensiveness of investigations of earthquake impacts, including performance of the built and socioeconomic environments
- Application of new information technology to data collection
- Data management and archiving.

The plan recommends that NEHRP develop standard formats for the collection of data on the performance of buildings and other structures in regions of severe ground shaking, including damage to nonstructural components and information characterizing the earthquake resisting properties of structures. The standard formats for data collection shall consider those already developed for existing damage prediction tools, such as HAZUS©, as well as current standardized procedures for seismic design, pre-event evaluation and rehabilitation, and post-event evaluation and repair of structures. All post-earthquake data also should be both collected digitally and stored in a virtual Web-based archive. This new database, though maintained at individual centers, would be retrievable from a single or mirrored Internet site using time stamps and a georeferencing system. The database would be addressable with all of the tools of a modern geographic information system as well as modern relational database technology on the Internet. NEHRP also should involve a wider range of disciplines, including economics, sociology, and political science, in post-earthquake investigations. Protocols for data collection in these disciplines also should be standardized.

Because much of this information helps to reduce future losses, it is recommended that domestic post-earthquake investigations for each event be funded by enacting a new section to the Stafford Disaster Relief and Emergency Assistance Act that would provide funding equal to one percent times the Section 406 disaster relief funds; administration of these funds would be by FEMA. The proposed modification of the Stafford Act would support appropriate post-event investigations of all disasters including natural and terrorist events.

2. Purpose

This report presents a plan to coordinate domestic and foreign post-earthquake investigations supported by the National Earthquake Hazards Reduction Program (NEHRP). As has been demonstrated in numerous disasters, authoritative and timely scientific and engineering advice after a disaster both improves emergency response and helps allay public fears and anxiety. Large urban earthquakes in the United States can cause large numbers of fatalities and great property loss. It is likely after a great earthquake that the Nation will turn to officials of NEHRP for authoritative advice following these inevitable events. By coordinating its post-earthquake response, NEHRP will be in a stronger position to provide input and work effectively with officials involved in the post-earthquake activities.

Major earthquakes also provide critical information on the earthquake process, ground shaking, and the performance of the built and socioeconomic environments. A set of coordinated response activities during and following the event can enhance the information acquired. The nature and quality of this information can significantly reduce losses not only immediately following the specific event, but also from future events through improved planning, design, and construction. The infrequency of large damaging earthquakes and the many NEHRP-supported investigators who can be expected to conduct field studies after earthquakes require that post-event investigations be closely coordinated in order to maximize learning that will improve mitigation of effects caused by future earthquakes. Post-earthquake investigations are critical for:

- Providing insight into why and how faults rupture
- Understanding and predicting shaking and secondary ground deformation
- Documenting and improving performance of the built environment
- Evaluating the adequacy of current building standards and practices
- Documenting societal and economic impacts and providing information for improving earthquake response and recovery activities
- Identifying specific opportunities to mitigate the impacts of future earthquakes.

In summary, benefits of post-earthquake investigations can include improved emergency response, a safer built environment, cost-effective construction of new structures and rehabilitation of older ones, improved land-use practices, and better understanding of earthquake hazards in the United States.

This plan provides a framework for coordinating what is going to be done and identifying responsibility for post-earthquake activities. It does not and cannot specify what will be done, because each earthquake offers different challenges and learning opportunities. The plan applies primarily to the Federal NEHRP agencies[1] and their partners, which range from state agencies, regional institutions, the Earthquake Engineering Research Institute (EERI), the NSF-funded centers and organizations for earth science and earthquake engineering research and education, the Network for Earthquake Engineering Simulation (NEES), to other academic and professional groups with professional interests in post-earthquake investigations. It is important to recognize that NEHRP post-earthquake activities primarily consist of information gathering and documentation of what happened. While some information is of immediate interest to emergency

[1] Agencies funded directly by NEHRP are the Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology (NIST), National Science Foundation (NSF), and the U.S. Geological Survey (USGS).

managers, the responsibilities of NEHRP in emergency response are modest. The primary responsibility is to alert the public and Federal and state agencies about the occurrence and scope of the event. Emergency response primarily is the responsibility of local and state governments and FEMA.

In addition to proposing a structure to improve coordination of the activities and investigations that typically are conducted following significant earthquakes, the plan also identifies new activities, some of which are permitted by advances in technology, that are considered significant to improve loss reduction in future earthquakes. These activities and a mechanism for their funding are described in four recommendations. Their implementation would substantially improve the contribution of NEHRP post-earthquake investigations to earthquake risk reduction in the United States.

Earthquakes are one of several hazards that can cause large human disasters and great loss. The most significant of these are hurricanes, floods, winter storms, tornadoes, wildfires, volcanic eruptions, landslides, and terrorist attacks. Indeed, from 1992 to 1996, losses in the U.S. from natural hazards averaged about $1 billion per week[2]. Post-event documentation of these hazards and their consequences contributes significantly to improvements in mitigating their impact and thereby reduces future losses. Although scientific and technical aspects of these hazards may differ, post-disaster investigations pose many similar challenges. Thus, this plan for post-earthquake coordination should be useful for planning and coordinating investigations of these other hazards.

3. Background

The 2001-2005 NEHRP Strategic Plan[3] stresses the importance of post-earthquake investigations. NEHRP has long supported post-earthquake investigations including efforts in the earth sciences, engineering, and socioeconomic disciplines. Improved coordination is necessary if these investigations are to maximize learning through the sharing of information. Because the U.S. Geological Survey (USGS) has the statutory responsibility and authority under Public Law 101-614 to conduct post-earthquake investigations, the Strategic Plan tasks NEHRP under the leadership of the USGS to (1) examine the roles and responsibilities of the various groups involved in post-earthquake investigations and (2) develop a NEHRP protocol action plan as well as a funding mechanism for investigations following major domestic and foreign earthquakes. According to the Strategic Plan, the NEHRP protocol action plan should detail the degree of coordinated learning desired, how those findings will be obtained, and how findings can be most effectively disseminated to all stakeholders in a comprehensive, multidisciplinary NEHRP report. The objectives of the present plan are to improve coordination during post-earthquake investigation efforts, minimize duplication of efforts, identify activities that could be supported with additional resources (such as disaster funds from the Federal Emergency Management Agency (FEMA) or supplemental appropriations) and maximize the opportunity to learn from both domestic and foreign earthquakes.

To develop the NEHRP protocol action plan, the USGS requested the assistance of the Applied Technology Council (ATC) of Redwood City, California, under USGS cooperative agreement 1434-WR-97-AG-00015, ATC-35. ATC organized a multidisciplinary 7-member

[2] Fact Sheet, Natural Disaster Reduction Initiative, U.S. Office of Science and Technology Policy, July 1997.
[3] FEMA, 2002(?), *Expanding and Using Knowledge to Reduce Earthquake Losses*: *The National Earthquake Hazards Reduction Program Strategic Plan 2001-2005*, Federal Emergency Management Agency,. Washington, D.C.

committee to draft the plan and a multi-institutional oversight committee to review the plan. Input was solicited from experienced post-earthquake investigators and NEHRP agencies at an invitational workshop held March 13-14, 2001, in Menlo Park, California. The workshop was jointly sponsored with EERI. Based on input from the workshop, a draft plan was prepared. In addition to the review by the oversight committee, comments were solicited from the general post-earthquake investigation community on a draft posted on the ATC Web site. The present plan is the result of this manifold input and comment process.

4. NEHRP Post-Earthquake Coordination Plan

The plan addresses coordination during three time frames or phases after the earthquake:

- Phase I, the post-earthquake reconnaissance during the first few days
- Phase II, the intensive gathering of perishable data during the first few weeks
- Phase III, the research and investigations conducted during the subsequent months and years.

The response of NEHRP to domestic and foreign earthquakes is sufficiently different in scope that earthquakes occurring in the United States and abroad are treated separately. Domestic earthquakes provide NEHRP with its best opportunity to evaluate seismic hazards and the performance of the built and socioeconomic environments in the United States. Furthermore, NEHRP is directed to conduct investigations of domestic events by the 1977 Earthquake Hazards Reduction Act. Consequently, domestic earthquakes typically receive greater scrutiny by NEHRP than do foreign earthquakes. Foreign earthquakes, however, usually provide insight into crustal failure processes, seismic radiation fields, and some construction practices that contribute to earthquake risk mitigation in the United States as well as opportunities for model validation. For example, about $1.5 million in NEHRP funds was used to support U.S. research investigations of the 1999 Kocaeli, Turkey and Chi-Chi, Taiwan, earthquakes. In some cases, such as the 1988 Spitak, Armenia, and the 1999 Kocaeli, Turkey, earthquakes, the affected countries request specific technical assistance from the U.S. Government, and these requests are usually fulfilled by NEHRP agencies.

4.1 Domestic Earthquakes

The proposed plan to coordinate post-earthquake investigations for significant domestic earthquakes is shown schematically in Figure 1. For the purpose of implementing the plan, either in part or in total, a significant domestic earthquake will be defined as follows: (a) an earthquake resulting in a Presidential disaster declaration or (b) an earthquake considered by NEHRP agencies to provide an opportunity to learn how to reduce future earthquake losses in the United States. The plan identifies the steps and approximate time line necessary to achieve coordination goals as well as the parties responsible for each activity. The responsible parties include NEHRP agencies, entities funded either in part or totally by NEHRP, and other entities with whom NEHRP should coordinate. As shown in the figure, these activities are parts of a continuum. Initial or Phase I post-earthquake activities focus on defining the scope of the disaster and are reconnaissance in nature. They identify research opportunities that will improve the practice of earthquake risk mitigation, set the stage for subsequent in-depth data gathering, and aid emergency managers by identifying hazardous situations that may be exacerbated by aftershocks or other processes. These Phase I activities are typically followed by more intensive data

gathering for subsequent research and analyses. This period is commonly referred to as Phase II and may last for weeks after the event. Phase III is the longer period after the earthquake when comprehensive research and investigations are conducted.

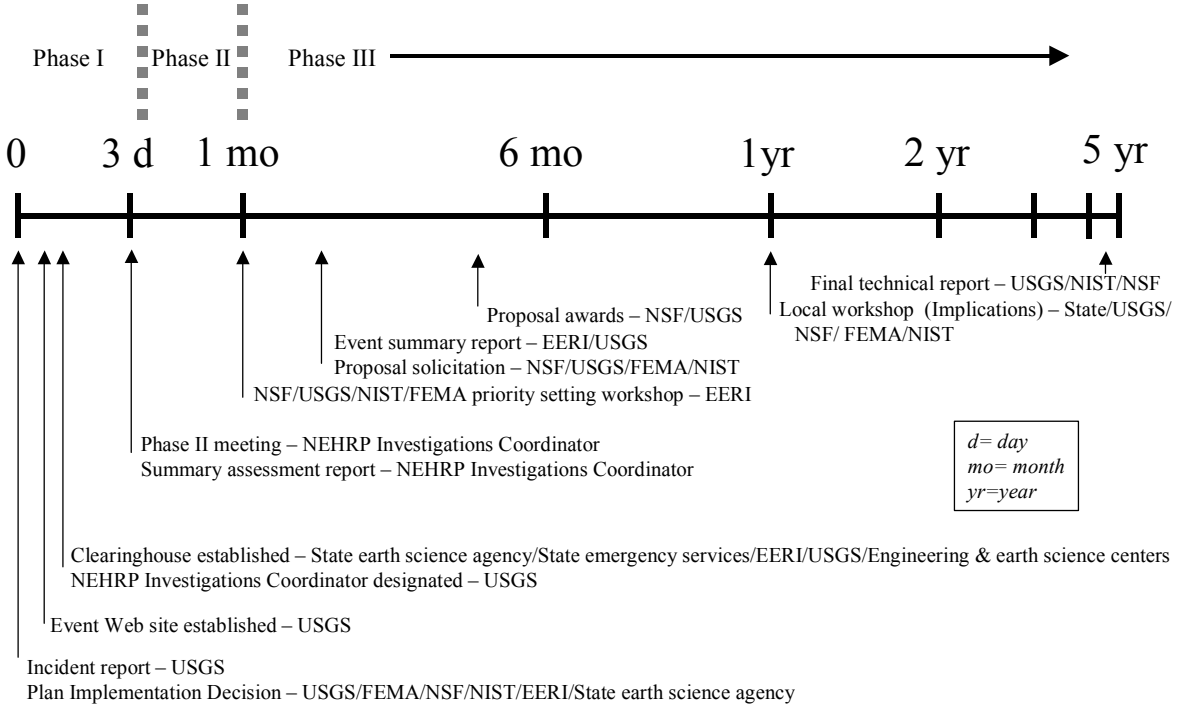

Figure 1. Activities Time Line for NEHRP Post-Earthquake Coordination Plan – Domestic Earthquakes.

Most of the activities identified in the plan are currently conducted by NEHRP after domestic earthquakes. The plan is designed to place them into a more formal structure. Some of the activities, particularly those that apply new information technology, are evolving with each earthquake. For these activities, the plan tries to anticipate their evolution and assign responsibility for their implementation.

4.1.1 Phase I

4.1.1.1 Incident Report and Plan Implementation (USGS)

When a large or potentially damaging earthquake occurs in the U.S., the USGS shall determine and announce the magnitude and location of the earthquake within minutes. As is the current practice, emergency response personnel should be alerted through the National Warning System (NAWAS), which is operated by FEMA. As development of the Advanced National Seismic System (ANSS) improves the USGS capability to estimate the strength and geographic

distribution of strong shaking, the USGS shall provide information about the potentially affected area[4]. Each NEHRP agency shall identify (and review annually) a contact who shall be alerted directly by the USGS about the event. Each NEHRP agency also should develop a list and strategy for contacting entities that have partnership responsibilities in the area of post-earthquake investigation. Examples of such entities include EERI, state geological surveys, earth science centers, and NSF-funded centers for earthquake engineering research and education. These entities should request that the USGS provide automatic e-mail alerts, which can be received on cell phones, pagers, etc.

The USGS following the incident report shall consult with the NEHRP agencies, the state geological survey(s) in the affected state(s), and EERI to determine if the earthquake is significant. If the earthquake is deemed significant, the USGS in consultation with the preceding agencies and organizations shall decide whether to implement all or part of the NEHRP post-earthquake coordination plan.

4.1.1.2 Web Site Management (USGS)

Beginning with the devastating earthquake in 1995 in Kobe, Japan, the Internet has become an important source of information about earthquake disasters for both technical personnel and the public. Under the plan, the USGS shall be responsible for establishing, within hours of a significant earthquake, an event Web site with links to other Federal and non-Federal earthquake-related Web sites. The USGS has recently automated this process for any domestic magnitude 6.5 or greater earthquake or a foreign earthquake of magnitude 7.0 or greater; smaller events may still be significant, however, and regional earthquake information centers will need to adopt and modify the automatic posting criteria to best meet the needs of their region.

To facilitate searches for the event Web site, its URL and a link shall be posted on the USGS Earthquake Program Web site (http://earthquake.usgs.gov) and the EERI Web site (http://www.eeri.org). The event site shall include brief descriptions of each linked site so that earth scientists, engineers, and social scientists will be able to search efficiently for information about the earthquake. Entities that are funded by NEHRP agencies and that establish Web sites shall be instructed by their funding agencies to inform the USGS of their URL and provide the USGS with a brief description or abstract of the Web site. The USGS event Web site also shall include information about the location of and activities at the technical clearinghouse (see 4.1.1.3). The Web site shall include authoritative sources of information; the USGS, EERI, and FEMA have responsibility, respectively, for earth science, engineering, and Federal disaster information and assistance. The USGS shall have principal responsibility for collating and linking to earth-science information. EERI shall have principal responsibility for collating and linking to engineering information as provided by the engineering centers, institutions, and private practice.

The USGS Earthquake Program along with the USGS regional and National Earthquake Information Center (NEIC) Web sites will be critically important sources of basic information for the news media and general public in the first few hours following a damaging earthquake. Commonly the demand for information surges several orders of magnitude during this period. In the past, the USGS has had difficulty in meeting this surge in demand; accordingly the USGS

[4] USGS, 1999, *Requirement for an Advanced National Seismic System*, U.S. Geological Survey Circular 1188, 55 p.; Wald, D., Wald, L., Goltz, J., Worden, B., and Scrivner, C., 2000, "Shake Maps" – Instant maps of earthquake shaking: U. S. Geological Survey Fact Sheet 103-00, 2 p.

has recently contracted with a private vendor for web content distribution. It is important that the USGS continue to employ a web-content distribution strategy that is scaleable and designed to perform well during peak periods. This will insure that the media, the general public, and responding officials, all have information about what happened as soon as it is available.

4.1.1.3 Technical Clearinghouse (EERI, USGS)

Within one day after a significant earthquake, a place should be established near the earthquake where post-earthquake field investigators can meet to review progress and to organize and coordinate their activities. For very large events, multiple places might be appropriate. Such a field facility, known as a technical clearinghouse, is increasingly becoming part of the post-earthquake investigation culture in the United States. Formal clearinghouses were established after the 1994 Northridge, California, and 2001 Nisqually, Washington, earthquakes. Establishment of the technical clearinghouse is paramount to ensure an orderly post-earthquake technical reconnaissance that does not interfere with emergency response activities. To meet this goal, direct communication between the clearinghouse and state and Federal Disaster Coordinating Officers needs to be established and maintained. The State of California has formalized the process for establishing a clearinghouse, with the principal NEHRP-sponsored participants being FEMA (Region IX), EERI, and the USGS[5]. Recently, the Western States Seismic Policy Council (WSSPC) and CUSEC have sponsored efforts to formalize the clearinghouse process in their regions. WSSPC recently adopted a policy that "each state, province, and territory establish a plan for post-earthquake clearinghouses to be activated within 24 hours after each major earthquake…"[6] and published a model plan (http://www.wsspc.org/publicpolicy/committees/clearinghouseplan.pdf).

The USGS, FEMA, and EERI shall work together on behalf of NEHRP and develop a general procedure for establishing a clearinghouse within 24 hours following a significant earthquake. The procedure shall be formulated in collaboration with state emergency management, state geological surveys, and appropriate regional agencies. The degree of leadership or responsibility by NEHRP entities for a specific event will depend on the level of involvement of non-Federal agencies in the clearinghouse. In cases where the states have a clearinghouse plan and resources, a state may take the lead in establishing the clearinghouse with NEHRP and its affiliated agencies being partners in that effort. In other cases where states are not prepared to establish a clearinghouse, NEHRP shall take the lead in establishing the clearinghouse with participation as available from state and local agencies.

Both the specific design and operation of the clearinghouse are the responsibility of the participants, but general operational plans must be prepared in advance by the USGS, FEMA, and EERI if a fully functional clearinghouse is to be quickly established. With regards to NEHRP-supported investigations, EERI shall take responsibility for the engineering and socioeconomic aspects of the operation and the USGS shall take responsibility for the earth science aspects. It is crucial that NEHRP funding agencies encourage funded centers, groups, and individuals to coordinate their activities with either EERI or the USGS through the clearinghouse. It is especially important that academic investigators, students, and technical

[5] Anon, 1998, *California Post-Earthquake Information Clearinghouse (draft)*: California Office of Emergency Services, Sacramento, California, 23 p.
[6] Western States Seismic Policy Council, 2001, Policy Recommendation 01-3, *Post-Earthquake Technical Clearinghouses*, WSSPC, Palo Alto, California.

representatives of the earthquake engineering research and education centers (Mid-America Earthquake Center (MAE), Multidisciplinary Center for Earthquake Engineering Research (MCEER), and Pacific Earthquake Engineering Research Center (PEER)) and earthquake earth science centers and organizations (SCEC, CERI, the Incorporated Research Institutions for Seismology (IRIS), and the University NAVSTAR Consortium (UNAVCO)) contribute and participate in the coordination efforts. These centers and organizations comprise a valuable assembly of multi-disciplinary expertise in earthquake investigations. In addition, students from these centers can gain first-hand experience and provide valuable support to the technical clearinghouse. USGS shall formalize agreements with the major NEHRP affiliated earth science centers and organizations to facilitate coordination; EERI shall formalize agreements with the major NEHRP affiliated engineering centers. It is critically important that these centers and organizations develop plans for post-earthquake investigations and share them with EERI and the USGS. Finally, at the time of an event, it may be useful to encourage participation by faculty and students from nearby universities and colleges, who are not affiliated with either earthquake engineering or earth science centers or organizations.

Both the operational relation and physical proximity of the technical clearinghouse to the Disaster Field Office (DFO) need to be considered when the clearinghouse is established. Some information collected during the Phase I activity may be relevant to decisions being made at the DFO. Coordination of the clearinghouse with the DFO may also provide a basis for a state's request that the clearinghouse be given a mission assignment by the appropriate state emergency services agency and thereby qualify the clearinghouse for partial funding support from disaster relief funds authorized by the 1974 Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended (42 U.S.C. 5121, *et seq.*).

If the earthquake is substantial and receives prominent coverage by the news media, many foreign researchers can be anticipated to visit. The USGS, EERI, and state agencies shall arrange at the clearinghouse to welcome, orient, and possibly brief these visitors about potential sites for their inspection and study. Close coordination between U.S. and foreign efforts can augment U.S. expertise and provide assistance with NEHRP post-earthquake investigations. Information directing visiting scientists and engineers to the clearinghouse should be posted on the event Web site.

4.1.1.4 NEHRP Investigations Coordinator (USGS)

Within one day of a significant earthquake, a NEHRP Investigations Coordinator shall be designated by the USGS. The USGS shall maintain a list of suitable candidates, both in and out of the Federal Service, and ensure that a mechanism is available to retain the full-time services of each individual on short notice for a minimum of one month. Actual selection shall be done in consultation with the other NEHRP agencies. The Coordinator shall be an individual with broad technical background, previous post-earthquake investigation experience, and a thorough awareness of the capabilities of the various NEHRP agencies and their affiliated centers and organizations. The Coordinator working in conjunction with scientific and engineering leaders must identify critical investigations and gaps in the ongoing investigation. Because it is impossible to delegate authority to the Investigations Coordinator under NEHRP, program managers in each NEHRP agency must work closely and cooperatively with the Coordinator to take advantage of the broad perspective of the Coordinator.

The advent of the Internet has greatly facilitated timely communication and reporting during natural disasters. Most organizations involved in post-earthquake investigations routinely provide daily situation reports on findings, progress, and difficulties encountered. Most of these reports are issued as e-mail. The Coordinator shall be (1) informed by each NEHRP agency about the scope of their post-earthquake investigation, and (2) included in all e-mail reports from field personnel and planning staff when possible. The Investigations Coordinator must also be kept abreast of activities at the technical clearinghouse.

Responsibilities of the Investigations Coordinator are to:

- Work with NEHRP and state agencies to ensure that news releases are consistent and helpful to the public.
- Ensure that liaison with appropriate state and local government is established if a state agency has not established the liaison responsibility. If a state liaison is in place, the Coordinator should ensure the liaison person is aware of NEHRP efforts if the clearinghouse has not fulfilled this need.
- Work with the liaison and technical clearinghouse to avoid potential conflicts between NEHRP technical efforts and emergency response and recovery management, and to ensure relevant assessments from the field investigators are appropriately communicated to emergency managers.
- Identify duplication and gaps in initial field reconnaissance and work with NEHRP and state agencies to rectify shortcomings.
- Convene and report results from Phase II meeting (see 4.1.2.1).

4.1.2 Phase II

4.1.2.1 Phase II Meeting (NEHRP Investigations Coordinator)

When initial reconnaissance activities have been completed and initial assessments of earthquake effects and damage have been made, typically within a few days to a week, it will be the responsibility of the Investigations Coordinator to convene a meeting to identify opportunities and needs for further investigation and concentrated data gathering. This meeting should involve leaders of the field efforts and include representatives from EERI, USGS, FEMA, NIST, NSF, earthquake engineering research and education centers, earth science centers, IRIS, UNAVCO, state agencies, and groups representing the earth science, engineering, and social sciences communities. The meeting is referred to in figure 1 as the Phase II meeting. The primary purpose of the meeting is to identify important or unique geologic and seismologic effects, damage to the built environment, and societal impacts for which concentrated short-term investigations and data gathering are required to ensure that important information is collected before it is lost or obliterated. It is particularly important to identify opportunities to collect important perishable data, such as data on structural and lifeline performance, aftershocks, and ground failure including fault rupture and secondary deformation. These are investigations that must be conducted quickly before effects and damage are obliterated by recovery efforts and natural processes. In retrospect, important data have been lost that could have been used to develop better engineering criteria and other hazard mitigation tools. As a consequence, valuable lessons were not learned and many needed tools to reduce losses and casualties have not been developed.

Within 24 hours after the meeting, the Investigations Coordinator shall prepare a brief summary of the meeting for the NEHRP agencies that describes (1) major preliminary findings of the reconnaissance teams and (2) opportunities for further investigations identified by participants in the meeting. The report shall include an estimate of the level of additional support required to pursue these opportunities. Based on the report of the Investigations Coordinator, NSF, the USGS, EERI, the earthquake engineering research and education centers and earth science centers shall work with the Investigations Coordinator to optimize the collection of perishable data.

If recommendation 4 to increase the level of post-earthquake funding is implemented (or if supplemental funds are appropriated), it is recommended that a joint statement of opportunity for directed data collection be posted on the USGS and EERI event Web sites soliciting statements of qualifications and funding requests from groups or organizations willing to conduct data gathering. This statement of opportunity should specifically identify urgent investigations and note that funding decisions will be made quickly by the process described in recommendation 4. Data gathering teams responding to this statement of opportunity will typically include professors and students, representatives from both the earthquake engineering research and education and earth science centers, representatives of state and Federal agencies, personnel from professional organizations, and groups from engineering and other private firms.

If recommendation 4 is not implemented (or if supplemental funds are not appropriated), the report should be used by the Investigations Coordinator to take maximum advantage of available resources. These resources include those by (1) NSF, which both supplements existing research contracts and awards Small Grants for Exploratory Research (SGER), (2) the USGS, which redirects agency personnel and their research funding, and (3) the earthquake engineering and earth science centers, which provide support from discretionary funds. In addition, the NSF award to EERI to support the Learning from Earthquakes Program now includes funding for a few small grants for post-earthquake data collection. Because these resources are collectively modest and typically do not provide for comprehensive documentation of earthquakes damage and effects, it is imperative that they be directed towards investigations of highest priority. This will require that these institutions work with the Coordinator before making awards.

4.1.3 Phase III

4.1.3.1 Workshop for Setting Investigation Priorities (NSF, USGS, FEMA, NIST)

Establishing priorities for long-term investigations, development, and implementation strategies following significant earthquakes is an important challenge for NEHRP. Large damaging earthquakes typically provide many opportunities to improve the understanding of earthquakes and their impacts. The NEHRP agencies (NSF, USGS, NIST, and FEMA) and appropriate state/regional agencies shall jointly sponsor a workshop of earth scientists, engineers, and social scientists within one to two months of significant earthquakes to discuss priorities for long-term (Phase III) research and development opportunities presented by the earthquake. The format adopted in the EERI workshops following recent foreign earthquakes is a possible model that might be supported by NEHRP. These EERI two-day workshops have served effectively to identify the most promising research opportunities – those that have the greatest potential to improve the current state of knowledge and practice throughout the world's seismic zones. The results of the NEHRP Workshop will be presented immediately afterwards in a report that

identifies major needs and opportunities for investigation, with a recommended set of priorities for funding.

Within the constraints of available funding, a joint statement shall be issued soliciting long-term research and investigations. Funding shall be made within approximately 5 months of the event. The Investigations Coordinator shall ensure that internal post-earthquake research activities of the USGS and NIST are coordinated with externally supported research of the NEHRP funding agencies.

4.1.3.2 Information Dissemination (USGS, NIST, NSF, FEMA)

The publication and dissemination of findings from NEHRP post-earthquake investigations currently are both inconsistent and incomplete. Research findings are published in a wide variety of journals in a more or less timely manner, but official publications of the participating organizations often are not available until years after the event. This significantly reduces their potential impact, both on earthquake-related knowledge and on loss-reduction policy. This plan envisions that three different types of publications will be issued either under the aegis of or with facilitation by NEHRP for every significant domestic earthquake. These are not meant to preclude publication of institutional reports like those currently prepared after significant earthquakes.

- **Three-month Event Summary:** An event summary for a broad audience shall be published within 3 months of the event. The summary should be well illustrated, comprehensive, and integrate preliminary observations on the seismological processes controlling the event and the response of the natural, built, and socioeconomic environments. We recommend that the event summary be prepared with formal collaboration of EERI and the USGS, but include NIST and other NSF-funded entities. For example, the contributions of all of the major engineering and earth science investigative efforts supported under NEHRP should be integrated and incorporated. Co-editors from contributing agencies and centers shall be included to facilitate agency participation. The summary is intended as a multidisciplinary document covering the earth sciences, engineering and social sciences. It is not intended to substitute for institutional reports such as the EERI reconnaissance report, the USGS circular, and center reports that currently are produced following significant earthquakes.
- **One-Year Conference Proceedings:** Because of the opportunity to implement change in the aftermath of disasters, FEMA, NIST, NSF, and the USGS will encourage and support local and state agencies in sponsoring a public conference with a proceedings on the one-year anniversary of a significant earthquake. The conference should identify and synthesize the policy implications of the event for earthquake risk reduction. NEHRP agencies shall participate and provide support to the state agencies as needed to promote a successful conference. The conference and proceedings would be analogous to transportation disaster assessments by agencies like the National Transportation Safety Board, which investigates transportation accidents to determine causality or the 1995 Earthquake Information Exchange Workshop held following the 1994 Northridge, California, earthquake. The anniversary conference should be held in the region impacted by the earthquake and the content of the conference should be designed to target an audience of local and state policymakers. It is also expected that NEHRP will sponsor technical conferences, as is the current practice.

- **Comprehensive Synthesis (3 to 5 years):** A comprehensive report that consists of one or more volumes that synthesizes the results and findings from studies carried out by the research and professional practice communities shall be published within 3 to 5 years of the event by the USGS and NIST, with assistance from NSF and FEMA. The cost of this publication shall be shared among the NEHRP agencies. The report shall emphasize the significant contributions of the post-earthquake investigations to the knowledge base on earthquakes and earthquake loss reduction and bring relevant data together in a summary fashion. The report shall be coordinated with the data archive discussed later (See Recommendation 3) where detailed investigations of representative structures, including plans, design criteria, estimated force distributions, and displaced shapes could be presented. The report should contain overviews of important findings derived from research on earth sciences and on the built and socioeconomic environments. This synthesis should include an extensive bibliography of the post-earthquake publications and should focus both on damage and disruption and on situations where the built environment performed well and little or no damage occurred. A comprehensive Phase III synthesis is important for several purposes to researchers and practitioners including providing both rapid entrée into the literature on the earthquake and overviews of studies that have been conducted in different disciplinary areas. A synthesis also distills significant lessons learned for future research, practice, and loss-reduction policy. Finally, NEHRP shall publicize the report to both the research and practice communities.

4.2 Foreign Earthquakes

NEHRP supports investigations of foreign earthquakes because they often provide special opportunities to validate models and to learn about both the performance of specific aspects of the built environment and the geologic and seismologic processes that will have implications for earthquake risk mitigation in the United States. Cost and logistics generally limit the size of NEHRP foreign post-earthquake investigations. Federal agencies generally do not participate unless officially invited by the impacted country. These factors cause tremendous differences in the character of individual investigations. At one extreme, investigations are modest and limited to small EERI reconnaissance teams, as for example, with the 1992 Erzincan, Turkey, earthquake. At the other end of the spectrum, affected foreign governments request U.S. assistance and these investigations have foreign policy implications, as with the 1988 Armenia, USSR, 1995 Kobe, Japan[7], and 1999 Kocaeli, Turkey, earthquakes. In the latter situation, some of the investigating teams are representatives of the U.S. government while others, who are not covered by the request, are independent.

Failure to coordinate schedules of field teams may lead to interference with the work of local experts and is the principal operational issue for NEHRP-supported foreign deployments. U.S. institutions typically respond independently in the earth sciences, engineering, and social sciences. Field parties supported by the EERI Learning from Earthquakes Program, the three earthquake engineering research and education centers (MAE, MCEER, and PEER), SCEC, CERI, IRIS, UNAVCO, as well as individuals with small NSF grants for exploratory research (SGER) may all visit earthquake-damaged areas with Federal funding support. In addition, the

[7] In this case, the Japanese request for U.S, governmental assistance was delayed for more than a month following the event.

USGS and NIST and private firms from both the U.S. and foreign countries and research entities from foreign countries commonly deploy field teams. These uncoordinated deployments of U.S. citizens have prompted complaints by affected countries to the U.S. Department of State.

In its recent award to EERI for the Learning from Earthquakes Program, the Civil and Mechanical Systems directorate of NSF (NSF/CMS) requested that EERI coordinate investigators funded by that directorate. In investigations in Turkey in 1999 and India in 2001, EERI has increasingly served as a point of contact for foreign post-earthquake investigations. This plan recommends that NEHRP expand this EERI role. This plan recommends that NEHRP agencies request that all U.S. post-earthquake investigators that they support inform EERI of plans and schedules of their investigations before departure as well as their ongoing status once they are in the field. EERI shall report these planned activities and their status regularly to the NEHRP agencies. Because authority to influence schedules rests with the NEHRP funding agencies, the agencies shall review proposed plans for their potential impact on the proposed country.

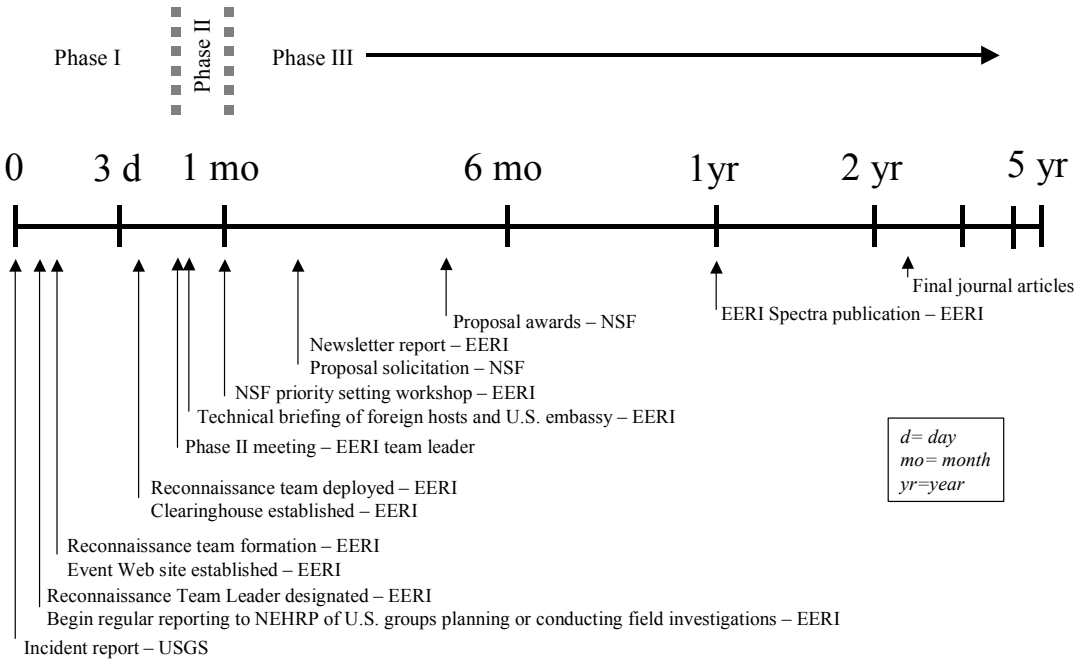

Figure 2. Time Line for EERI Post-Earthquake Activities – Foreign Earthquakes

We note that EERI in its LFE Proposal has strengthened the coordination role of the EERI Team Leader and group leaders for each of the disciplines. In the field they solicit collaboration with other investigators. In preparing the preliminary and final EERI reports, they solicit and coordinate contributions from others who participated in field investigations. The EERI Team Leader also plays a significant role in helping to coordinate the second phase of data collection by making contact with each of the investigative teams before they enter the field and

maintaining contact with them during the field investigations via e-mail and phone. The EERI Team Leader offers to direct these investigators to areas that require further investigation before perishable data are lost. The approach allows researchers to collect data in several waves, improving the comprehensiveness of the documentation of earthquake impacts. Coordinating field investigations and drawing on contributions from other teams ensures a clear understanding of damage and impacts, less duplication, less disruption of local emergency response and research efforts, more effective utilization of limited research funding, and a more comprehensive report on the earthquake. The EERI post-earthquake investigation plan is shown in Figure 2.

5. Recommendations for Further Action

At the March 13-14, 2001, invitational workshop held to provide input for this draft plan, participants identified several aspects of NEHRP post-earthquake investigations that are deficient. These deficiencies diminish the potential contribution of NEHRP to risk reduction in the United States. Areas in need of improvement include the following:

- **Comprehensiveness:** Investigations of earthquake impacts do not comprehensively cover all aspects of the natural, built, and socioeconomic environments.
- **Efficiency:** Emerging new information and technologies can greatly increase the quality and quantity of data collection, while lowering costs.
- **Data storage and retrieval:** Much of the data that has been collected in historic earthquakes has been effectively lost. If data collection is to become even more comprehensive, data management, archiving, and linking to existing data must be improved.

The following recommendations propose solutions to these interrelated deficiencies. The objectives of the first 3 recommendations are to improve the scope (Recommendation 1), the quality and quantity (Recommendation 2), and the utility (Recommendation 3) of data acquired during post-earthquake investigations. Recommendation 4 proposes a mechanism for funding these improvements.

5.1 Recommendation 1: Broaden Coverage and Comprehensiveness of Investigations of Earthquake Impacts

Issue – Impacts on built and socioeconomic environments are not well documented

Research on the impacts of earthquakes on the *natural environment* (for example, seismology, ground motion, and permanent ground deformation) is relatively well organized and documented by NEHRP because the USGS has both budgetary and operational responsibility in this area. The result has been significant improvement by both USGS and non-USGS scientists in the basic understanding of the natural consequences of earthquakes such as shaking and permanent ground deformation.

In contrast, performance data on the *built environment* (for example, buildings and lifelines) are not systematically compiled. Documentation of the seismic performance of non-structural components in facilities is particularly lacking. This failure to document fully the physical impacts of an earthquake has serious consequences because full-scale testing of the performance of engineered systems under dynamic loading is often impractical. Since damaging

earthquakes are infrequent, each failure to systematically document damage is a lost opportunity to improve:

- Performance-based design
- Loss estimation
- Safety assessments of badly damaged structures.

The current trend in earthquake engineering is to base seismic risk evaluations and design decisions on the predicted behavior of structures and their components during assumed levels of earthquake ground shaking. This approach, called performance based earthquake engineering, shows great promise as a framework to enhance the ability of both the private and public sectors to identify and to quantify levels of risk, to develop cost-effective strategies for risk reduction activities, and to implement efficient seismic rehabilitation. Yet these techniques rely completely on assumptions on the part of engineers of the actual performance of the built environment. An overly optimistic view can overlook significant risks or lead to ineffective designs. In the other extreme, excessive conservatism leads to unnecessarily high costs or, worse yet, inaction in the face of a seemingly insurmountable problem. Effective decisions on the part of building owners and managers, insurance and financial institutions, and public policy makers require realistic predictions of expected behavior in a statistical context. Extensive documentation of actual behavior, good and bad, of a broad range of structures subjected to real earthquakes will provide the data to meet this critical need.

These data that document performance of the built environment are also essential for improving earthquake loss estimation models. Predictions of earthquake impacts with computer-based loss estimation models are becoming increasingly common in both the private and public sectors because the rarity of large damaging earthquakes does not permit robust actuarial estimates of future losses. Comprehensive documentation of the impacts of future earthquakes will improve model-based estimates of structural and nonstructural damage, casualties, and financial loss.

Documentation of the performance of the *socioeconomic environment* also is very incomplete. Increasingly post-earthquake investigations include social, organizational, and economic issues, but much more progress is needed. For example, despite their obvious importance, relatively little emphasis is currently being placed on the systematic collection of data on earthquake-related deaths and injuries, both for U. S. and foreign earthquake events. The same can be said for other topics of major societal relevance, including the organization and effectiveness of emergency response and relief activities and the short- and long-term social and economic impacts of earthquakes, including impacts on regional economies, communities, households, and businesses.

Potential Solutions:

Built Environment:

Two aspects of structural performance surveys are particularly important: (1) adequate inventories of the building stock and others structures at risk and (2) systematic documentation and compilation of both damaged and undamaged structures. The lack of adequate inventories in many cases hampers assessment of the significance of observed damage. Inventories make it

possible to characterize the damage data and place it in proper context. For example, the knowledge that 1,000 steel buildings in the 1995 earthquake in Kobe, Japan, suffered significant damage is incomplete information. How many steel buildings were subject to strong ground shaking? Where were the damaged buildings located relative to the fault?

Fortunately, with the increasing application of standardized procedures for seismic design of structures, pre-event evaluation and rehabilitation of structures (see FEMA 310[8] and 356[9]), post-event evaluation and repair of structures (FEMA 306/307/308[10]), and damage prediction (FEMA 154[11], HAZUS©[12]), a framework is emerging in the United States for both the collection of performance data and the development of inventories. For example, HAZUS©, which was developed by FEMA to standardize loss estimates from earthquakes and other natural hazards, provides a framework for inventories of facilities and the description of performance. This plan recommends that NEHRP adopt a format for documenting performance that is consistent with these methodologies. It is also recommended that NEHRP through FEMA also promote the development of robust inventories of structures by working with HAZUS© users groups and others who have adopted and adapted these procedures. Important work in these areas is already ongoing at the NSF-funded earthquake engineering and research and education centers.

This plans recommends that the systematic documentation and compilation of damaged and nondamaged structural performance, as well as the earthquake resisting properties of structures be spearheaded by NIST because the data also would ultimately be used to improve building codes and standards and practices for structures and lifelines, a responsibility of NIST. The format for this documentation shall be established by NIST before the next earthquake and could be similar to the ATC-38 post-earthquake building performance assessment form[13] and the EERI clearinghouse report form[14]. In the absence of implementation of our Recommendation 4 for supplemental funding, it is unclear who will fund the post-earthquake damage surveys. The actual surveys could be conducted by a contract with engineering organizations such as American Society of Civil Engineers (ASCE), National Council of Structural Engineers Association (NCSEA), and ATC under the supervision of NIST.

The extensive and detailed information on the damage to facilities that is routinely compiled by FEMA as a part of the disaster assistance funding process is an existing valuable

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[8] ASCE, 1998, *Handbook for the Seismic Evaluation of Buildings – a Prestandard*, prepared by the American Society of Civil Engineers for the Federal Emergency Management Agency, FEMA-310 Report, Washington, DC.
[9] ASCE, 1998, *Prestandard & Commentary for the Seismic Rehabilitation of Buildings*, prepared by the American Society of Civil Engineers for the Federal Emergency Management Agency, FEMA-356 Report, Washington, DC.
[10] ATC, 1998, *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual*: prepared by the Applied Technology Council for the Federal Emergency Management Agency, FEMA-306 Report, Washington, DC;
ATC, 1998, *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings, Technical Resources*:, prepared by the Applied Technology Council for the Federal Emergency Management Agency, FEMA-307 Report, Washington, D.C.;
ATC, 1998, *Repair of Earthquake Damaged Concrete and Masonry Wall Buildings*: prepared by the Applied Technology Council for the Federal Emergency Management Agency, FEMA 308 Report, Washington, DC.
[11] ATC, 1988, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: a Handbook*, prepared by the Applied Technology Council, ATC-21 Report, for the Federal Emergency Management Agency, FEMA-154 Report, Washington, D.C.(FEMA-154, 2nd Edition is in Preparation)
[12] HAZUS, 1999, Hazards United States: Washington, D.C., National Institute of Building Sciences.
[13] ATC, 2000, *Development of a Database on the Performance of Structures near Strong-motion Recordings: 1994 Northridge, California*, Earthquake, Applied Technology Council, ATC-38 Report, 245 p.
[14] S. McAfee, written comm., 2001; EERI, 1996, *Post-Earthquake Investigation Field Guide; Learning From Earthquakes*: Oakland, CA, Earthquake Engineering Research Institute, Publication 96-1, 144 p.

source of information that is not being utilized for research purposes. Coordination with FEMA to capture these data would provide a large source of additional data[15]. Once the collection of data on the built environment is improved, the data must be appropriately archived and made available. This can be accomplished by promotion of a NEHRP database (see Recommendation 3).

Socioeconomic Environment:

A wider range of disciplines and specialists also needs to be incorporated into post-earthquake reconnaissance activities. Although there has been movement in the direction of greater disciplinary diversity, post-earthquake reconnaissance activities are undertaken primarily by earth scientists and engineers. Groups that remain underrepresented in post-earthquake investigations include public health specialists (such as epidemiologists), researchers from the various social science disciplines (for example, economics, sociology, geography, and political science), and experts from the emergency management and public policy communities.

Mechanisms must be established to encourage greater participation by investigators with expertise in the social science and public health fields, experts in economic modeling and geographic information systems, and others who can contribute to the collection and analysis of data on the pre- and post-impact social environment. NEHRP should coordinate and work with organizations involved in studying the socioeconomic and public health aspects of disasters to recruit and train a cadre of qualified health and social science investigators who can participate in future post-earthquake studies. A partial list of these organizations include the U. S. Centers for Disease Control and Prevention, the University of California at Los Angeles Center for Public Health and Disasters, leading social science centers such as the Natural Hazards Research and Applications Information Center at the University of Colorado and hazard-focused geographic information system (GIS) laboratories such as the Hazards Research Lab at the University of South Carolina, and professional associations such as the International Research Committee on Disasters. As an initial step, EERI should initiate outreach efforts aimed at informing social science and public health researchers about NEHRP-related post earthquake data collection opportunities and more effectively integrate members of these groups into post-earthquake investigations.

EERI should also seek input from social scientists on how to improve the quantity and quality of data that are collected on the societal aspects of earthquakes. As is the case with other disciplines involved in post-earthquake investigations, new protocols are needed to ensure that the data-collection strategies and instruments that are used to obtain data on the social, economic, and health impacts of earthquakes are standardized, so that comparisons can be made across time and across earthquake events. Existing documents such as the EERI *Post-earthquake Investigation Field Guide* outline in broad terms the types of social and economic impact data that should be obtained during the post-earthquake reconnaissance phase. This guide should be reviewed, revised, and expanded to incorporate a broader range of social science data as well as to provide more systematic frameworks for recording those data. When revised, the guide should be distributed widely within the social science research community.

[15] Previous studies have emphasized the need for systematic collection and compilation of economic impacts (see National Research Council, 1999, The Impacts of Natural Disasters – A Framework for Loss Estimation: Washington, D.C., National Academy Press, 49 p.

Agencies that sponsor post-earthquake investigations should also recognize that gaps in knowledge exist because many disciplines and topics lack adequate funding. In making funding decisions, NEHRP agencies should examine how to ensure better disciplinary coverage so that significant research topics—including those focusing on the socioeconomic environment—are not overlooked. Both the Investigations Coordinator and the entities responsible for organizing the Phase II and III meetings to set priorities shall be responsible for ensuring that significant socioeconomic issues are included in the research plans that are developed and that adequate funding is available to support that work. Finally, societal impact data must be placed in a larger context, for example through the systematic collection of data on both pre- and post-event characteristics of affected communities, populations, and economies.

5.2 Recommendation 2: Encourage Use of Information Technology

Issue – Information Technology (IT) offers opportunities to improve collection of data

Data that are amenable to collection via remote sensing, digital imaging, global positioning system, and other new and emerging technologies are distributed widely within the natural, built and social environments. A wide variety of data, which previously could not be collected or only collected at great effort, can now be collected and analyzed rapidly, often in near-real time. Examples include the following:

- Regional geodetic and geological effects
- Recordings of strong shaking on the ground and in engineered structures during the main shock
- Aftershock rates and statistics
- Ground deformations associated with faulting, liquefaction, landslides, and shaking
- Direct and indirect damage to structures and lifelines (both in a regional statistical sense and in detailed studies of selected structures)
- System responses, such as pressures and flows in gas, water, and wastewater systems, telephone demand surges, and traffic patterns
- Collateral dynamic phenomena, such as growth and spread of post-earthquake fires and spills of hazardous materials
- Data on earthquake casualties and on other social and economic impacts.

Potential Solution:

Rapid advances in information technologies now permit rapid, cost-effective collection and analysis of virtually exhaustive data sets in each of the above categories. A few examples of current, but only recently available technologies include the following:

- **PDA-GPS-Digital Camera Technology** to permit standardized but rapid and extensive digital descriptions of georeferenced damage data for regional and detailed structure and lifeline damage studies.
- **Remote Sensing** (for example, InSAR, LIDAR) for compilation of inventories of the visible built environment before and immediately after the main event, for regional assessments of damage

- **Digital Recording and Near-Real-Time Dissemination of Strong Shaking Measurements** throughout the affected built environment during the occurrence of damage from the main earthquake to provide the quantitative recordings needed for emergency response, performance based engineering, and the rebuilding of a safer society
- **High-resolution Low-altitude Vertical and Oblique Aerial Photographs** as a mandatory part of the NEHRP post-earthquake reconnaissance, to be made available free on the Internet
- **On-Site Digital Video Image Capture** via special image-capture vans with digital cameras mounted to document building status on both sides of the street immediately following the event
- **SCADA Data** for understanding of the real-time impacts and response to earthquakes of distributed systems such as gas, water, and wastewater systems. Supervisory Control and Data Acquisition (SCADA) systems have emerged as a typical feature of lifeline networks over the last several decades – the data are generally available but have been little used for studying the effects of earthquakes, damage and post-earthquake response, and demands on the systems.

It should also be mentioned that while not observational data, both ShakeMap and HAZUS© results can be valuable adjuncts to post-earthquake investigations (in addition to emergency response). Existing GIS inventories of the built environment can guide comprehensive inspection and data collection for essential facilities and infrastructure.

These are only a few examples of relatively new technologies that can be used more effectively in post-earthquake investigations. IT is developing so rapidly that new tools and applications are emerging constantly. In order to enhance post-earthquake investigations and analyses, we recommend that NSF, USGS, NIST, and FEMA support ongoing research into applications of IT and ways to analyze and use the collected data. The NSF-funded earth science organizations and earthquake engineering research and education centers provide excellent resources for this effort. We also recommend that, in the immediate response to the event, NSF, USGS, NIST, and FEMA support equipment and other resource needs and facilitate access to and use of selected IT assets that may be beyond the resources of individual investigators (for example, if FEMA tasks national reconnaissance assets to fly over a domestic earthquake, to the maximum extent feasible the imagery should be available to NEHRP-supported investigations).

5.3 Recommendation 3: Formalize Data Management and Archiving

Issue – Collected data are not well archived and therefore are effectively lost

It is critical to develop strategies for the formal and systematic archiving of data collected during post-earthquake investigations. These data, which focus on the natural, built, and socioeconomic environments, address a wide variety of phenomena. The data are voluminous and are acquired in many forms (for example, digital recordings, digital images, clipboard survey sheets, photographs, and narratives). If not organized and archived soon after an earthquake event, these data are often lost. No mechanism currently exists either to archive these data or to make them readily accessible to the research community. Because of this failure to adequately document, preserve, and access data, an enormous volume of highly relevant data has been effectively lost.

Potential Solution

Management of these data requires:

- **Research on cost-effective field data collection**. Much of the initial data from post-earthquake investigations are collected on foot in the field. Use of georeferenced personal digital assistants and digital and video cameras with GPS capability, and other efficient data collection tools should be encouraged by the development and free dissemination of standardized software applications and associated data protocols, for use both in the field and for downloading data.
- **Development of a consensus-based repository** for collected data. Rather than relying on physical repositories, technology now permits most data to be digitally recorded and stored. Therefore, this plan recommends the creation of a virtual web-based archive, analogous to the structure and functioning of the Consortium of Strong-Motion Observation Systems (COSMOS) Virtual Data Center (http://db.cosmos-eq.org/). This new database, to be called the *National Earthquake Experience Database* (NEED) should be maintained at individual centers, but retrievable from a single or mirrored Internet site using time stamps and a geocoded referencing system. NEED would be addressable with all of the tools of a modern GIS as well as modern relational database technology on the Internet. Researchers could contribute to it from any location, according to established quality control guidelines. NEED will fill the need for a permanent, interactively managed national and international archive for the unprecedented data sets to be collected from future damaging earthquakes.

One approach to this effort would be to have each recipient of NEHRP funding (NSF grants, the earthquake centers, USGS awards, NIST, and others) be required to budget a percentage of the grant funds (for example, 1 or 2 per cent) for archiving raw and reduced data in NEED. Alternatives for management and maintenance of NEED include:

(a) NEED could be integrated into and managed by Network for Earthquake Engineering Simulation (NEES), which is currently forming a Consortium that could accommodate NEED.
(b) NEED could be resident in the National Information Service for Earthquake Engineering (NISEE), and overseen by a board consisting of representatives of organizations such as MCEER, PEER, MAE, EERI, Seismological Society of America (SSA), ATC, and Consortium of Universities for Research in Earthquake Engineering (CUREE). NEED could reside on the NISEE server with mirror servers on the MAE, MCEER, and PEER servers.

The costs associated with implementing the above two measures range from research funding focused specifically on the integration of new technologies into post-earthquake investigations, to providing funds for a workshop where investigators share information on their data collection and archiving strategies, to supporting a Web site where data-sharing will be accomplished. Each level of effort has an associated cost. Once the data repository format has been established, implementation of a consensus-based repository can be accomplished. Dedicated costs for creation and maintenance of NEED would be perhaps two staff-years to start, and one staff-year annually thereafter, with hardware and expenses perhaps in the tens of thousands of dollars annually. Contribution of data into NEED would be a distributed cost, borne

by each contributing investigation. We recommend all NEHRP-supported investigations be required to budget a small fraction of the investigation's overall costs for this purpose.

5.4 Recommendation 4: Commit One Percent of the Stafford Act Disaster Funds to Support Post-Earthquake Investigations

Issue – Funding of post-earthquake investigations is inadequate

The absence of readily available financial resources to fund immediate, short-term, and long-term post-earthquake investigations has resulted in the failure to collect valuable data vital for development of earthquake disaster reduction measures and has handicapped substantial follow-up research investigations. For the 1989 Loma Prieta, California, earthquake Congress enacted "Emergency Supplemental Funds" for use by the NEHRP agencies for post-earthquake investigations. The emergency supplemental funding provided by Congress following the 1989 Loma Prieta earthquake was $20 million, of which $8 million was designated for post-earthquake investigations administered by USGS. The emergency supplemental funding provided by Congress following the 1994 Northridge earthquake was $13 million. It was recognized that this is neither the best nor the most efficient means to fund these efforts [16]. The report to Congress by FEMA[17] requested in the 1990 reauthorization bill provides an excellent summary of the benefits of post-earthquake investigations and suggests several alternative approaches to establishing a fund for this purpose. It was clear that the four principal NEHRP agencies could not agree on a single best approach.

Potential Solution

We recommend that funding for domestic post-earthquake investigations be obtained through the Stafford Disaster Relief and Emergency Assistance Act and be administered by FEMA. Foreign post-earthquake investigations will continue to be funded on a basis of need from each of the NEHRP agencies.

Recommended Funding Solution: It is proposed that a new section be enacted to the Stafford Act that provides funds for immediate, short-term, and long-term post-disaster investigations. We recommend that the amount of funds be equal to one percent times the Section 406 disaster relief funds[18]. For the Loma Prieta earthquake this would have amounted to about $28 million and for the Northridge earthquake it would have totaled about $60 million. It is recognized that this change in the Stafford Act would also provide post-disaster funds for disaster-related investigations following other disasters, including floods, winter storms, tornadoes, wildfires, volcanic eruptions, landslides, and terrorism.

Recommended Administration: It is recommended that FEMA be responsible for the identification of investigation topics, distribution of the funds, and reporting of the results to Congress[19]. For earthquake disasters it is recommended that the NEHRP Policy Coordinating Group, Presidentially appointed individuals from the four principal NEHRP agencies, appoint a

[16] Public Law 101-614, National Earthquake Hazards Reduction Program (NEHRP) Reauthorization Act, Section 11(b), November 1990

[17] FEMA, January 1993, Funding Post-Earthquake Investigations: Report to Congress.

[18] Section 404 current provides between 15 and 20 percent times the 406 expenditures for hazard mitigation. For the Northridge earthquake this amounted to about $722 million.

[19] Hazard-mitigation projects funded by Stafford Act Section 404 are selected by the state for which the disaster has been declared and approved by FEMA before expenditure.

nine-member post-earthquake investigation Selection Committee prior to the earthquake disaster. This Committee would be mobilized within days after the earthquake, attend all briefings, participate in the joint NSF/USGS/FEMA/NIST priority-setting workshop, and be responsible for identifying the basic and problem-focused investigation efforts required to maximize learning from the specific disaster. Based on the outcomes and recommendations of the workshop, the Committee would recommend to FEMA topical areas and funding levels for each area. FEMA would determine the funds to be allocated to each NEHRP agency. Each agency would have the responsibility to identify appropriate projects and investigators, administer grants, provide project supervision, and account for funds spent in their topical areas. They will actively contribute to the report to Congress. The nine members of the Selection Committee would consist of one member from each of the four principal NEHRP agencies and five members from the non-Federal earthquake community.

6. Annual Review of Plan

The United States historically has been fortunate that large damaging urban earthquakes have been infrequent. This is due more to the relatively recent development of the United States, than to a lack of seismicity. Potentially damaging earthquakes, such as the 1811-1812 New Madrid sequence in the Midwest, the 1755 Cape Anne, Massachusetts, and 1886 Charleston, South Carolina, events on the east coast, the 1857 Fort Tejon event in southern California, and the 1700 mega-event in the Pacific Northwest, are all well documented, but occurred before major urban or suburban development of the regions. In modern times, the only large ($M>7$) earthquakes that affected U.S. cities were the 1906 San Francisco and 1964 Good Friday Alaska events, both of which devastated cities.

Smaller ($M<7$) but more frequent modern events, however, such as the 1971 San Fernando, 1989 Loma Prieta, 1994 Northridge, and 2001 Nisqually earthquakes, offer opportunities to learn how to reduce earthquake risk – the ultimate goal of NEHRP. Thus, possibilities to implement the proposed plan in its entirety will occur periodically. As normal turnover in NEHRP management occurs, however, new managers may be unfamiliar with the Plan. The problem is further compounded because NEHRP lacks a line-management structure to activate this Plan immediately after an event.

Therefore, we recommend that the NEHRP Interagency Coordinating Committee (ICC) review the Plan annually, and after each review remind agency and institutional managers of their obligations under the Plan. We recommend that this annual review occur on the anniversary of the largest recorded earthquake in U.S. history, the March 27, 1964, Good Friday earthquake in Alaska.

The annual review would provide opportunities to revise or modify the plan as appropriate. A fundamental tenet of emergency management is that the process and currency of planning are as important as the plan itself.

Appendix 1. Terms and Acronyms

ANSS, Advanced National Seismic System
ASCE, American Society of Civil Engineers
ATC, Applied Technology Council
COSMOS, Consortium of Strong-Motion Observation Systems
CERI, Center for Earthquake Research and Information
CUSEC, Central United States Earthquake Consortium
CUREE, Consortium of Universities for Research in Earthquake Engineering
DFO, Disaster Field Office
EERI, Earthquake Engineering Research Institute
FEMA, Federal Emergency Management Agency
GIS, Geographic Information System
GPS, Global Positioning System
HAZUS, Hazards United States
ICC, (NEHRP) Interagency Coordinating Committee
InSAR, Interferometric Synthetic Aperture Radar
IRIS, Incorporated Research Institutions for Seismology
IT, Information technology
LIDAR, Light detection and ranging
MAE, Mid-America Earthquake Center
MCEER, Multidisciplinary Center for Earthquake Engineering Research
NAWAS, National Warning System
NCEA, National Council of Structural Engineers Associations
NEED, National Earthquake Experience Database
NEES, Network for Earthquake Engineering Simulation
NEHRP, National Earthquake Hazards Reduction Program
NEIC, National Earthquake Information Center
NIST, National Institute of Standards and Technology
NISEE, National Information Service for Earthquake Engineering
NSF, National Science Foundation
NSF/CMS, National Science Foundation, Civil and Mechanical Systems
OFDA, Office of Foreign Disaster Assistance
PDA, Personal Digital Assistant
PEER, Pacific Earthquake Engineering Research Center
SCADA, Supervisory Control and Data Acquisition Systems
SCEC, Southern California Earthquake Center
SGER, Small NSF grants for exploratory research
SSA, Seismological Society of America
UNAVCO, University NAVSTAR Consortium
USGS, United States Geological Survey
WSSPC, Western States Seismic Policy Council