

Coordinating NEHRP Post-Earthquake Investigations—Exercising the Plan

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Three exercises of *The Plan to Coordinate NEHRP Post-Earthquake Investigations* were developed and implemented in late 2003 and early 2004 in order to test the Plan itself via realistic scenarios, and for the NEHRP agencies to learn how to coordinate post-earthquake investigations. The exercises were selected to cover a range of seismic activity and consequences, and were based on scenario events: (1) a Hayward Fault M_w 7 event without foreshocks; (2) a New Madrid seismic zone M_w 7 event with foreshocks, and (3) a Puerto Rico M_w 8 subduction event on the Puerto Rican Trench accompanied by a tsunami affecting the eastern seaboard of the United States. Each exercise consisted of a four-hour telephone conference call with a Web-based electronic link and post-exercise evaluations fed back to participants. Evaluation of the exercises found the Plan to be adequate, with implementation of the Plan by the NEHRP agencies improving with each exercise. Based on the exercises, recommendations were provided that a Plan coordinator should be designated within USGS, an annual exercise of the Plan should be conducted in different regions of the United States, a permanent NEHRP electronic link should be created, and coordination of post-earthquake data collection, preservation, archiving, and dissemination should be greatly improved.
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INTRODUCTION

The National Earthquake Hazards Reduction Program (NEHRP) was established by the 1977 Earthquake Hazards Reduction Act as a long-term, nationwide program to reduce the risks to life and property in the United States resulting from earthquakes by supporting research and mitigation. NEHRP is administered by the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the United States Geological Survey (USGS). The 2001–2005 NEHRP Strategic Plan (*FEMA-383*) (FEMA 2003) directed the USGS, which has statutory authority to conduct post-earthquake investigations under the 1977 act, to develop a plan to improve the coordination of NEHRP post-earthquake investigations. As a result, *The Plan to Coordinate NEHRP Post-Earthquake Investigations* (the “Plan”) was developed by a committee working under the auspices of

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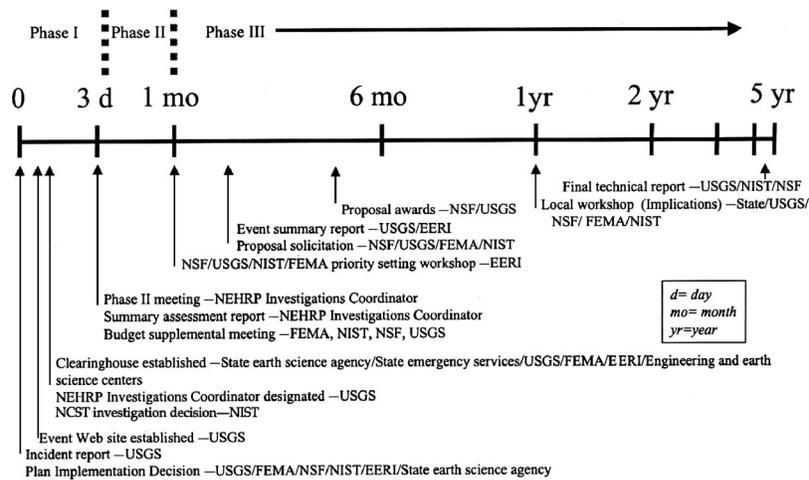


Figure 1. Activities timeline for NEHRP Post-Earthquake Coordination Plan—domestic earthquake (USGS 2003).

the Applied Technology Council (ATC) through a contract with the USGS. The Plan was published as *USGS Circular 1242* (USGS 2003). The planning process for development of the Plan began with an invitational workshop in 2001 sponsored by ATC, EERI, and the USGS.

This paper summarizes the Plan, and reports on the development and implementation of exercises of the Plan. The exercises were executed by ATC through a contract with the USGS and facilitated by the second author. The purposes of this paper include (1) informing the earthquake risk reduction community of the existence of the Plan, (2) detailing the process by which the Plan's exercises were developed and implemented, and (3) reporting the lessons learned and recommendations that resulted from the exercises. Information on the processes and resources required to develop and implement the exercises are also provided so that this information can serve as a resource for persons tasked with development and implementation of exercises of other response plans.

THE NEHRP PLAN—A SUMMARY

The purpose of *The Plan to Coordinate NEHRP Post-Earthquake Investigations* is to provide for the coordination of domestic and foreign post-earthquake investigations supported by the NEHRP agencies and their partners. Most of the emphasis of the Plan is on domestic U.S. earthquakes that either result in a presidential disaster declaration or are considered by NEHRP agencies to provide an opportunity to learn how to reduce future earthquake losses in the United States. The plan is a framework for both coordinating what is going to be done and identifying responsibilities for post-earthquake investigations. Coordination is addressed in various time frames ranging from hours to years after an earthquake (Figure 1). The Plan includes measures for gaining rapid and general agreement on high-priority research opportunities, and conducting the data gath-

ering and field studies in a coordinated manner. It deals with identification, collection, processing, documentation, archiving, and dissemination of the results of post-earthquake work in a timely manner and easily accessible format. The Plan organizes domestic post-earthquake investigation and information dissemination activities into three phases and a number of steps, each of which is a decision point within the Plan, that is, the NEHRP agencies at each step should decide whether the situation warrants further action or whether the coordination activities should be terminated at that point. In summary, the three phases and steps are as follows (for details, see USGS 2003):

- **Phase I (immediate to several days):** Incident Report and Plan Implementation; Web Site Management; Technical Clearinghouse; appointment of a temporary NEHRP Investigations Coordinator with broad oversight responsibilities; and National Construction Safety Team (NCST) Investigation.
- **Phase II (several days to one month):** Meeting to identify and report opportunities and needs for data gathering and investigation, and call for proposals for rapid investigations; Budget Supplemental Decision.
- **Phase III (one month to five years):** Workshop on Investigation Priorities, within one to two months; Investigations Solicitation; Information Dissemination; Event Summary Report published within three months of the event; Public Conference on the first anniversary of the earthquake; within five years, a comprehensive synthesis of research and professional report.

For foreign earthquakes, which typically are less intensively investigated than domestic earthquakes, the plan recommends that all U.S. post-earthquake investigators inform the Earthquake Engineering Research Institute (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 as well as on its web site. NEHRP agencies shall monitor these plans to avoid interference by visiting U.S. investigators with local experts.

USGS Circular 1242 concluded with recommendations that addressed several deficiencies in current domestic post-earthquake investigations. The deficiencies were identified at an invitational workshop of experienced post-earthquake investigators held in March 2001 as part of the process to prepare the Plan, and were in the areas of coverage and comprehensiveness of investigations of earthquake impacts, including performance of the built and socioeconomic environments; application of new information technology to data collection; and data management and archiving.

The Plan was written by a committee consisting of Thomas L. Holzer (chairperson) (USGS), Roger D. Borchardt (USGS), Craig D. Comartin (Comartin-Reis), Robert D. Hanson (University of Michigan), Charles R. Scawthorn (consultant), Kathleen Tierney (University of Colorado), and T. Leslie Youd (Brigham Young University). It was reviewed by each NEHRP agency and was published as *USGS Circular 1242* (USGS 2003).

EXERCISING THE PLAN—PURPOSE AND TASKS

Any plan is preparation for actual actions. When the time comes to take those actions, time and circumstances typically do not permit reference to the plan, so that to be effective, the plan's objectives and elements must be known beforehand by the parties who are responsible for acting. Additionally, any plan, that is not tried in some manner, is more likely to have flaws. Thus "exercises," or mock role-playing of a plan, are an essential part of both validating the plan and preparing participants for the future events that the plan addresses. Toward this purpose, exercising of the NEHRP Plan was supported by the USGS upon completion of the Plan through a contract with ATC, which retained the services of a facilitator. The exercising of the Plan was intended to involve neither all possible aspects of an investigation nor all persons and agencies who would eventually perform post-earthquake investigations. Rather, the exercises were bounded in the following manner:

- **Purpose of Exercises:** The purpose of the exercises would be (1) to test the Plan itself via realistic scenarios, and (2) to have the NEHRP agencies learn how to coordinate post-earthquake investigations. The exercises should not be about the technical aspects of the investigations, or even about what should be investigated.
- **Participants:** The exercises should be limited to ensuring familiarization of the Plan by key NEHRP agency personnel and their primary partners, who would be the persons coordinating post-earthquake investigations and responsibilities; all other invited participants would hopefully benefit from their participation, but would not be the focus of the exercises.
- **Time Frame:** Learning from earthquakes is an ongoing process, and the Plan reflects this in its five-year time frame (Figure 1). However, the Plan also recognizes that this five-year time frame will have three distinct phases: Phase 1 (immediate to several days), Phase 2 (several days to one month), and Phase 3 (one month to five years). Phases 2 and 3 allow time for thoughtful consideration and conferencing, but Phase 1 is the period during which key decisions made under time and other pressures set the path for subsequent phases. Thus Phase 1 was the focus of the exercise of the plan.

A careful reading of Phase I in the Plan indicates that a number of actions are called for. These are summarized in Table 1. The accomplishment of these actions as called for by the NEHRP Plan thus became the standard for the Plan's exercise; that is, an exercise served as both a test of whether the NEHRP agencies accomplished these actions as well as a device for the agency personnel to learn how to accomplish these actions. The remainder of this paper reports on how the exercises were designed, developed, conducted, and evaluated, and on the recommendations that resulted from the experience.

DESIGN OF THE EXERCISES

Design of the exercises involved deciding a number of parameters, such as how many exercises there should be, how each exercise should be conducted, what the time interval should be between exercises, and who should participate in the exercises. This section summarizes the decision-making process on each of these aspects.

Table 1. Actions called for during Plan Phase 1

No.	Time since EQ	Resp.	Action	Explanation of Action
1	Few minutes	USGS	Notify emergency managers, NEHRP agencies, state geological surveys	For domestic earthquake
2	Few hours	USGS	Convene Conference call with NEHRP agencies, state geological surveys, and EERI to determine if earthquake is significant	Significant defined as (a) Presidential Disaster Declaration or (b) considered by NEHRP agencies to provide an opportunity to learn
3	Few hours	USGS/ all	Decide whether to implement all or part of Plan	USGS in consultation with NEHRP agencies
4	Few hours	USGS/ state GS	If Plan is implemented, inform emergency managers of this decision	USGS in collaboration with state geological surveys
5	Few hours	USGS	Establish event web site (URL posted on EERI web site and http://earthquake.usgs.gov)	Links to other web sites
6		NEHRP agencies	Instruct grantees who establish web sites to inform USGS of URL	Only required if grantee establishes web site
7	1 day	USGS, FEMA, EERI	Establish Clearinghouse (CH) (multiple sites may be necessary—communication and proximity to DFO important)	State entities may be given major portion of responsibility, if capable
8	1 day	USGS	Designate NEHRP Investigations Coordinator (NIC)	List of candidates prepared in advance. NIC full-time on short notice for minimum one month.
9	2 days	NIST/ all	Decide to form NCST or not	NIST in consultation with NEHRP agencies. Need to define scope of investigation (what buildings or building types?).
10	3–7 days	NIC	Convene Ph II meeting to identify investigation opportunities and needs	Attendees: field leaders, USGS, FEMA, NIST, NSF, EERI, EERCs, IRIS, UNAVCO, earth science centers, state agencies, multi-state consortia, and others (see Plan)
11	1 day after Ph II mtg.	NIC	Written summary of meeting	Summary identifies major findings, opportunities for further investigation
12	ca. 10th day	All	If funds available, SOO posted on USGS, EERI, and NSF web sites	SOO= Statement of Opportunity, for urgent investigations, with rapid funding decision
13	Few days	All	Consider budget supplement request	
14	Ongoing	All	Keep NIC informed	
15	Ongoing	NIC	Identify duplication and gaps	

Number of Exercises: As noted above, exercises should serve both as a test of whether the NEHRP agencies accomplished the Plan actions, and as a device for the agency personnel to learn how to accomplish those actions. In order to allow opportunity for participants to learn the Plan, accomplish its actions, and demonstrate this ability, more than one exercise was needed. It was decided that three exercises were the minimum necessary to accomplish the project purpose. This was based on the consideration that (1) the first exercise would probably identify gaps in participant knowledge and ability, and that this identification would therefore teach participants what they did not know; (2) that a second exercise would permit participants to correct most errors and omissions, but that some might still exist; and (3) that a third exercise would confirm participants had corrected any errors and omissions identified in the second exercise. Another factor in the decision to conduct three exercises was that it allowed several regions of the United States to participate, covering the range of seismic activity, consequences, and NEHRP agency, state, and local experience envisioned in the Plan.

Participants in the exercise included representatives from NEHRP agencies and EERI, and parties these five entities invited. To improve the realism of the exercises, the NEHRP agencies and EERI were encouraged to invite participation by state and local agencies, academics, professionals, and any other entities or persons who they thought would be involved in and key to Phase 1 of a post-earthquake investigation. Collectively, all persons participating in an exercise are referred to as participants.

Conduct of Exercises: Given that each exercise might involve numerous personnel from NEHRP agency headquarters and regional offices, EERI, local officials, and others from the region in which the scenario earthquake occurred, it was decided on the basis of project resources that each exercise would be conducted via a telephone conference call, supplemented by an *electronic link*. Each exercise would be led by a facilitator. The electronic link consisted of a web site facility that permitted all participants to log on to a web site, read and write to a "chat board," and see and mark up graphics posted by the facilitator. The electronic link permitted real-time display of maps and other figures, and also real-time written communication among participants. The specific electronic link facility employed for the exercises was a commercial service, typical of those available from numerous vendors. Given time zone differences and other factors, it was decided that four hours would be an appropriate duration for each telephone conference call exercise. The four hours would represent Phase 1, that is, a period of several days.

Time Interval Between Exercises: The minimum time interval between exercises was governed by several considerations. Each exercise needed to be documented and evaluated, and the results communicated to participants. In addition, the script and details of the next exercise might need to be modified based on the evaluation. Given these considerations, it was determined that the minimum interval to allow these tasks to be accomplished was one month. Also, because real earthquakes requiring post-earthquake investigations by NEHRP could occur at any time, the project should be accomplished in as timely a fashion as possible.

Table 2. Scenario earthquake events

Scenario Earthquake Event	M_w	PGA 10% in 50 yrs	Affected Pop. (millions)	Hist. Max M_w /year	Comment
Hayward (N+S)	M_w 7	0.6	6.8	7.7/1906	Similar to <i>USGS OF 99-517</i>
New Madrid	M_w 7	0.4	7.7	7.8/1812	Similar to Dec 16, 1811 event
Puerto Rico	M_w 8	0.22	3.8	8.1/1787	Similar to 1787 event: subduction on Puerto Rican Trench

SCENARIO EARTHQUAKE EVENTS

Scenario earthquake events were selected that would engage the NEHRP agencies in the consideration, and possibly the implementation, of the Plan. While foreign earthquakes are considered in the Plan as warranting investigation, the degree of proposed coordination is less. Thus only domestic events were considered for the exercises. Based on this, the project defined three criteria for selection of scenario earthquake events:

1. A sufficient likelihood of the occurrence of the earthquake.
2. Data collection and research likely to lead to an improved understanding and mitigation of earthquakes and their risks would be warranted if the earthquake occurred.
3. The tectonic, built environment, organizational, governmental, and other conditions for the scenario were likely to be encountered during actual implementation of the Plan.

Based on these criteria, a simple algorithm was developed that considered the likelihood and severity of earthquakes, and the emergency response experience and capability, in most parts of the United States. The algorithm and its implementation are presented in the ATC final report (2005). Ten possible earthquake events were selected for analysis using this algorithm, which resulted in a grouping of the ten possible events into three categories: two California events; New Madrid and Pacific Northwest events; and events in Utah, Charleston, Boston, Anchorage, Guam, and Puerto Rico. One event was selected from each group, as the basis for an exercise. The three scenario earthquake events, presented in Table 2, are the following:

1. **Hayward Fault M_w 7 event**, resulting from a rupture of the northern and southern Hayward Fault segments as defined in *USGS Open-File Report 99-517* (USGS 1999). This was selected over a southern California event due to (a) it being perhaps the most likely significant event in California; (b) the presence of the fault on the Berkeley campus of the University of California; (c) the proximity of the fault to major infrastructure such as the Bay Area Rapid Transit system (including its tunnels through the East Bay Hills and under San Francisco Bay), major highways, the Port of Oakland, and East Bay Metropolitan Utility District and other water supply facilities; (d) the potential for major fires following the earthquake, as evidenced by 1906 San Francisco earthquake and

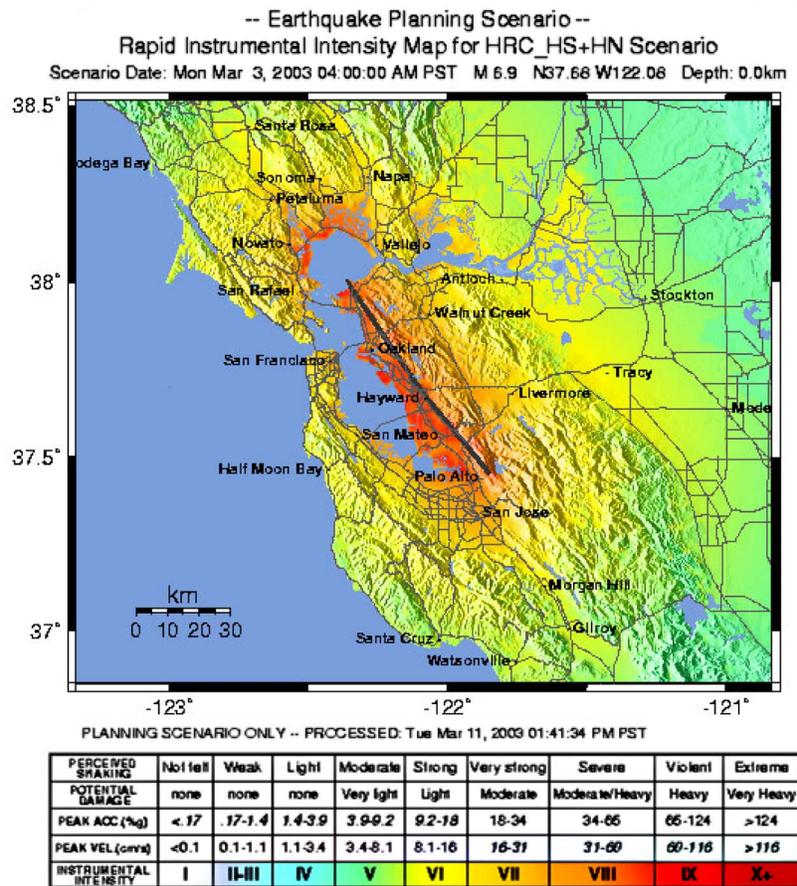


Figure 2. Hayward scenario earthquake (USGS).

the 1991 East Bay Hills fire; and (e) its potential adverse impact on EERI, a key participant in the NEHRP Plan. A ShakeMap for this event developed by USGS is shown in Figure 2. (Note: the figure is for a M_w 6.9 event).

2. **New Madrid seismic zone M_w 7 event**, similar to the 16 December 1811 event. This was selected over the Pacific Northwest event because it affects a region of the United States with a large population where many people have not experienced earthquakes. It was also a good test of the Plan where the scenario involved coordination across three to (perhaps) five or more state boundaries. The detailed scenario included several foreshocks.
3. **Puerto Rico subduction zone M_w 8 event**, on the Puerto Rican Trench, similar to the 1787 event. This was selected over the other events in the third category based on many factors, including (a) very poor soils and numerous high-rise buildings in San Juan being affected by a distant large event (similar in some

ways to the 1985 Mexico City earthquake, which resulted in numerous high-rise collapses); (b) the possibility of generating a tsunami, particularly in the Atlantic, where there is very little experience, and where it could affect the eastern seaboard of the United States, as well as other localities; (c) lack of familiarity by most U.S. investigators with Puerto Rico; and (d) logistical and, to some extent, cultural and linguistic obstacles for U.S. investigators, thus resembling in some ways a foreign earthquake.

All three events have historical precedents. The sequence of the exercise events was determined by the increasing organizational challenge to the NEHRP agencies. The events were exercised in the order of Hayward (M_w 7), New Madrid (M_w 7), and Puerto Rico (M_w 8).

Detailed definitions of the three scenario earthquake events and possible resulting consequences were developed as background for detailed exercise scripts based on these events, and are described in the ATC final report (2005). Each scenario event was detailed in terms of the season and time of day of the earthquake, the prevailing weather and other relevant conditions, and data on possible resulting consequences. The consequences were of course hypothetical, and based on a combination of information in the literature on possible consequences resulting from these or similar scenarios, as well as experience in other earthquakes. For example, from a Plan and exercise point of view, some key aspects of the first exercise (Hayward M_w 7 event) were that the event occurred in a relatively small area (major damage 20 miles by 100 miles), so that one technical information clearinghouse should suffice; the region has previously experienced earthquakes, and has a plan for establishment of a clearinghouse; there are a number of major earthquake institutions in the epicentral area, including the Pacific Earthquake Engineering Research Center, University of California at Berkeley (UCB), Stanford University, San Jose State University, Consortium of Universities for Research in Earthquake Engineering, Lawrence Livermore National Laboratory, Seismological Society of America, USGS Menlo Park, and insurance modeling firms EQECAT and RMS. EERI, one of the Plan's major participants, is headquartered in the area, and the script called for them to be initially out of operation so that they would need to exercise their backup plan; the Disaster Field Office (DFO) is set up in the Oakland Federal Building, so that either the State Office Building or an undamaged site on the UCB campus (which has many recently retrofitted buildings) could be chosen for a clearinghouse. Similar detailed definitions of the New Madrid M_w 7 event and Puerto Rico M_w 8 subduction event on the Puerto Rican Trench were developed and are available in ATC (2005). To incorporate a real element of surprise in the exercises, the choice and details of all scenario events were kept strictly confidential in advance.

PREPARATION, FORMAT, AND CONDUCT OF THE EXERCISES

Preparation for the exercises consisted of structured interviews with participants, development of scripts, and review of instructions and communication checks before each scenario. Structured interviews were conducted with each NEHRP agency and EERI for the purpose of obtaining their views on the NEHRP Plan and the planned exercises, understanding their current state of knowledge of the Plan, and identifying what they

hoped to learn from the exercises. The outcome of the interviews was that the agencies were familiarized with the Plan and the purpose, scope, and conduct of the exercises. Detailed exercise scripts were then developed that consisted of a minute-by-minute series of communications that the facilitator would verbally announce during the exercise's telephone conference call and, in many cases, also accompany with a figure transmitted via the electronic link. In order to introduce an element of surprise similar to an actual earthquake, participants in each exercise were told that the event would occur in one of two possible regions. Once announced, participants in the unaffected region were only allowed to observe. Actions required by the Plan were tabulated, and identified in the exercise scripts, and participants were required to state actions they took during the exercise. Comparison of actions taken versus actions required by the Plan would show whether the NEHRP agencies fulfilled, exceeded, or failed to implement the Plan.

An example of the first few minutes of the script for Exercise 1 is presented in Table 3. Complete final scripts, which averaged about a dozen pages per exercise, are presented in the project final report (ATC 2005). Instructions were four pages in length, and detailed the protocol for conducting the exercise, covering such items as purpose, participants, schedule, communications, communications check, electronic link, region, exercise agenda, auditors, speaker identification, recording, cell phones and beepers, participation, announcements, actions, and breaks. About a week prior to each exercise, a communications check ("Comm Check") was held for purposes of checking communications and reviewing the procedures for the exercises. NEHRP agencies were expected to inform any other participating personnel of these dates. The Comm Check telecon required approximately one hour and consisted of confirming that all parties could dial into the voice telecon and access the electronic link.

Exercises were conducted on 19 December 2003, 9 January 2004, and 10 February 2004. Each exercise was scheduled for 1 p.m. EST (10 a.m. PST), and was of four hours duration, with breaks about every hour. The three exercises involved 29, 43, and 43 participants, respectively, and generally followed the script with no major departures and with the great majority of participants attending during the entire exercise. Disruptions were virtually nil, due to several factors: the Comm Checks had eliminated telecom and electronic link difficulties, the general tone (of a serious group of professionals) had been set by the Comm Checks and instructions, and participants were asked to mute their telephones when speaking privately to colleagues at their site. Each exercise began with a roll call and initial announcement of an earthquake somewhere in the United States, followed by additional announcements at periodic intervals that presented the participants with an unfolding earthquake incident. Participants were free to confer and discuss the situation, their options, etc. in any manner, including using the electronic link to share data, figures, thoughts, and other information. All discussions and communications were open to all participants, and were recorded both via a voice recording of the entire telecon and via the electronic link. Examples of several of the numerous maps, photos, and "breaking news messages" from *ENN* (the Earthquake News Network) transmitted over the electronic link, are presented in Figures 2–4.

Table 4 provides an example of the text messages sent via the "chat" facility of the electronic link during Exercise 2. The exercise concluded with a second roll call at the

Table 3. Example exercise script—Exercise No. 1 Hayward Event

Exercise Time (mins)	EQ Local Time	Exercise Announcement	Actions by NEHRP Agencies, Anticipated by Exercise Planners						Action taken during Exercise?
			USGS	FEMA	NIST	NSF	OES	EERI	
ANNOUNCE START OF EXERCISE									
—		It is Saturday, 25 Oct., of some year in the near future. The Homeland Security Threat Level is <i>Elevated</i> (i.e., third of five levels). At any time, any participant should feel free to state an Action they are taking.							
0.30	Oct 25 12 noon	An earthquake has occurred, but only people feeling the event are aware of it.						self-anncmt	self-anncmt
1.00	1200.30	USGS NEIC (Golden) and S. Calif. Mgmt. Center, Pasadena, detect an event							
1.30	1203	Via DOD channels, the White House situation room is informed of a major earthquake in the San Francisco Bay Area, where it is a bright sunny day with strong offshore winds. Fire conditions are Very High.							
2.00	1203	Rumors are heard at the NY Stock Exchange and in Washington of something happening on the West Coast							
2.30	1204	First analysis by S. Calif. Mgmt Center, Pasadena indicates an M7 event centered near Oakland							
3.00	1205	Rapid earthquake information (REI) is automatically transmitted by SCMC via pagers and Web to selected persons							

We take you to ENN News Anchor Strong Temblor:

Temblor: *We are just receiving reports of a major earthquake in North California, possibly in the San Francisco Bay Area...*

Voiceover: *Strong, we apologize for interrupting, but we have local affiliate KSHK on the line:*

Voiceover: *This is KSHK's Happi Center, in Modesto – confidential sources inform us they've just picked up radio traffic from commercial airline pilots, saying they're being diverted to Los Angeles, due an earthquake in San Francisco. Furthermore, other sources are picking up traffic on police scanners, similarly talking of a huge earthquake in San Francisco.*

Temblor: *Thank you Happi. More at 1pm. This is Strong Temblor, ENN News Anchor.*



Strong Temblor

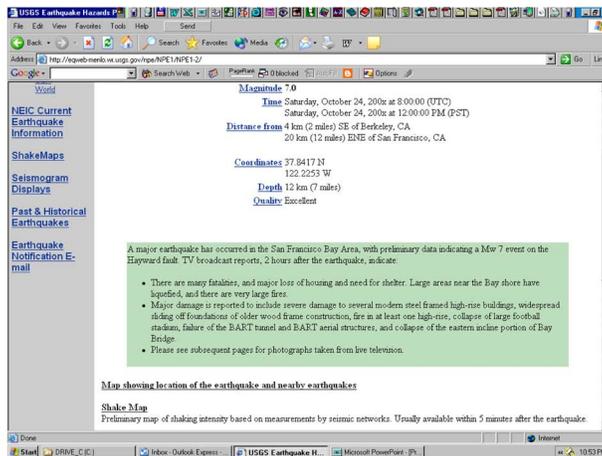
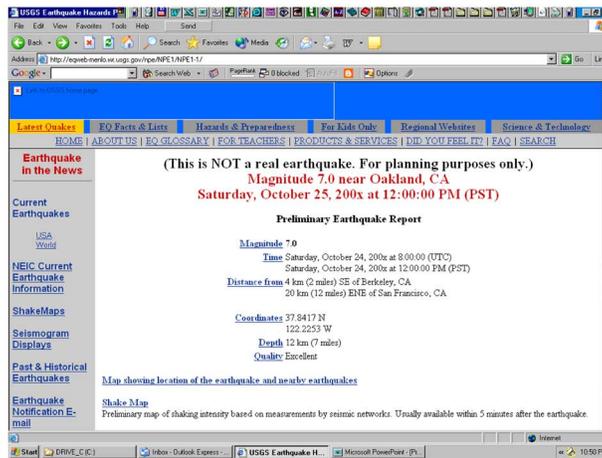


Figure 3. Exercise 1: Mock-up initial USGS web site.



Figure 4. Exercise 1: Mock-up first televised aerial photo, and ENN reporter “Strong Temblor.”

end of four hours clock time (i.e., at 5 p.m. EST), which represented about the seventh day of the scenario event. Following the formal conclusion of each exercise, a few minutes were allocated during the telecom for immediate verbal comments and feedback, and participants were also encouraged to communicate written comments and a critique. Verbal comments were almost entirely positive, and almost no written comments were

Table 4. Chat record of Exercise 2

NEHRP PLAN EXERCISE 2—9 Jan. 2004—Written Messages	
08:46:44 a.m. from FACILITATOR to All Participants	WELCOME TO THE 2nd NEHRP PLAN EXERCISE
09:10:27 a.m. from FACILITATOR to All Participants	It is Tuesday, 9 Jan., of some year in the near future. The Homeland Security Threat Level is HIGH (i.e., highest of five levels). At any time, any participant should feel free to state an Action they are taking.
09:10:57 a.m. from FACILITATOR to All Participants	0.30 Jan 9, 0900 An earthquake has occurred, but only people feeling the event are aware of it.
09:11:09 a.m. from FACILITATOR to All Participants	1.00 0903 via DOD channels, the White House situation room is informed of an earthquake in the Memphis area, where it is a bright sunny day with temperatures in the 20s (F)
09:11:45 a.m. from FACILITATOR to All Participants	2.00 0907 ENN and networks interrupt regular schedule to report an earthquake in the Midwest
09:12:34 a.m. from FACILITATOR to All Participants	2.30 0908 FEMA is alerted by the White House, and also picks up TV broadcasts. A pager alert is broadcast to key staff.
09:12:54 a.m. from FACILITATOR to All Participants	3.00 0910 USGS Golden has a Preliminary Determination of Epicenter (PDE), showing a M6.2 event south of Cape Girardeau, MO
09:13:17 a.m. from FACILITATOR to All Participants:	0911 Golden receives a call from FEMA, and reports the PDE
09:13:55 a.m. from FACILITATOR to All Participants:	0912 Golden calls the USGS Program Coordinator and reports a M6.2 event south of Cape Girardeau, MO
09:14:06 a.m. from USGS J. Gombert, B. Schweig to All Participants:	USGS Memphis calls CUSEC, Bob Bauer, and Norm Hester
09:16:34 a.m. from FACILITATOR to All Participants:	USER NAME npe PASSWORD reston
09:18:48 a.m. from FACILITATOR to All Participants:	0920 Golden continues analysis, initiates Notification Checklist, making calls to USGS offices, White House, DOD, TN/IL/AR OES, EERI, MCEER, MAE, PEER, USACE
09:19:08 a.m. from FACILITATOR to All Participants:	1000 By now, all four NEHRP agency persons responsible for the post-earthquake investigation coordination have seen TV footage, and made telephone calls, but have not yet conferred. None of them have been able to identify specific cases of major damage.

subsequently received. Full audio recordings and written transcripts taken from those recordings are included in the ATC final report (ATC 2005). A one-page sample transcript of the audio recording of Exercise 2 is presented in Table 5.

EXERCISE OUTCOME

A key outcome of Phase I of the Plan is the convening of a meeting to identify investigation opportunities and needs, including the consideration of a budget supplemental request. The last part of the exercise focused on this aspect, which of course was driven by the details of the scenario and script that the participants had been presented with. An example of the agencies' response to this requirement, drawn from Exercise 1, is as follows:

- NIST requested \$20 million to fund its response to the collapse of steel-frame high-rise buildings following the Hayward Fault earthquake. The investigation would focus on a specific steel high-rise building that the script indicated had sustained major damage, and a high-rise building in San Francisco where fire played a key role in the collapse. NIST chose not to investigate the scripted collapse of the UCB stadium (despite large loss of life there) due to its location directly on the fault. NIST's request also funded R&D, based on the findings of the investigation that *“will develop recommendations for improvements to practice, standards, and codes. The third part of the response will be dissemination and technical assistance to communicate the findings of the investigation and guidance for improvements to practices, codes, and standards.”*
- NSF identified three primary structural engineering areas of interest for future study: connections in steel frame buildings, bridge structures, and large multi-story residential structures. *“All have suffered significant damage and need study. A fourth area is geotechnical studies of landslides and liquefaction damage. Lastly, a fifth area is emergency response and social science issues, particularly access and control issues related to researcher access, study of citizen emergency response teams (CERTs), and effectiveness of local community pre-event recovery planning. We are requesting \$9 million for engineering research and \$2.5 million for emergency response and social science issues. A special research solicitation will be issued related to this event following the EERI workshop. Budget request would include investigation, R&D, and dissemination of investigation findings and R&D results. R&D would include best practices guidance on improvements to practice, standards, and codes. The effort includes building performance, evacuation, and emergency response procedures. It will draw on engineers, physical and social scientists, and experts in human behavior, evacuation, and fire protection.”*
- USGS's Supplemental Budget summary requested support for three items: (1) Investigations/Research that included fault rupture; strong motion data collection in the free field; rupture process (seismic & geodetic analysis); structural response data collection/analysis; ground failure: collection/analysis of field & instrumental data; aftershock studies; transient deformation analysis; aerial imagery; LiDAR imagery; shaking intensity surveys (working with local groups);

Table 5. Part of Exercise 2 audio recording transcript

CS:	It is 10:15. Radio stations have live interviews with New Madrid, Cape Girardeau, and Memphis fire chiefs. All provide similar reports, which is that it shook real good and have had a number of calls and runs but have not found much damage. This is News Anchor Strong Temblor; we have first pictures of earthquake damage in this morning's magnitude 6.2 earthquake north of Memphis. We see here damage to Farmer Brown's chimney, and here cracks in a levy on the Mississippi near Madrid. This is Strong Temblor, ENN News Anchor.
Unk.:	I'll take the action to call Lucy Jones at home in Southern California and ask her to evaluate the likelihood of this being a foreshock.
CS:	It's 10:30, FEMA Sitrep 1 is sent to all four NEHRP agencies—M6.2 earthquake occurred, TN, MO, and AR activated EOCs, hospitals in Memphis and Cape Girardeau activated emergency plans, several houses and farm buildings collapsed; MODOT reports two highway bridges with significant cracking; Memphis and many smaller communities report water main breaks. And I see that Jim Wilkinson has sent a message here, to people, I'm just calling attention to it.
JW:	Call received from Susan Tubbesing from EERI. Action: CUSEC is gathering reports from its member states on damage to infrastructure. CUSEC has notified Association of CUSEC state geologists to begin activation of regional post-earthquake investigation plan.
Unk:	According to our plan for post-earthquake technical information clearinghouse, it will be activated with earthquakes greater than 5.5 magnitude; therefore we have contacted the state surveys and the state emergency management agencies, the state DOTs in several states to get input for the selection of the sites.
BB:	This is Bauer in Illinois. We'd be contacting our Emergency Management Agency to say that we want to be associated with their forward command, where we'd most likely set up a clearinghouse.
CS:	It's 10:45. St. Louis radio station KROK broadcasts reports that seismologists are warning of possible large earthquakes in next few days, and that an army convoy with supplies, including 10,000 body bags, has left St. Louis headed towards Memphis.
JH:	This is John Hill, Indiana Geological Survey; I'm confused about the location of the earthquake. There seems to be conflicting information on the USGS web site. One topographic map site shows it near Blytheville, the other map shows it up near Sikeston.
CS:	You can see the information there and I'm trying to get the shake map on the Web facility. Okay, here's the shake map for the time being.
JK:	This is Jack Kuehn from the MAE Center. <cut out>
CS:	This is the facilitator. Okay, I've pasted the shake map into a white board on the left-hand side of your screen in the chat facility. Do people see that?
JK:	Yes.
CS:	You can now look at that as much as you wish at that scale. Sorry about that.
DA:	This is USGS Reston, following a complication on the phone call with the other NEHRP agencies. We've collectively taken the action to select Buddy Schweig as the NEHRP investigations coordinator for this event.

subsurface investigations (geophysics, seismic, borings); and a USGS-led update to earthquake probability assessment and urban-area hazards assessment for the San Francisco Bay region; (2) USGS products (reports, publications, maps, and GIS products); and (3) USGS instrument replacement and repair to network/communication. USGS total supplemental request was \$15 million. USGS would likely also propose to complete the ANSS and expand its base program, giving the ability to monitor earthquakes and create improved earthquake hazards assessments and response products nationwide (several tens of millions of dollars).

- The FEMA/DHS supplemental, based on the results of its Building Performance Assessment Team (BPAT), would identify several specific issues of concern that FEMA would conduct further research on. Issues could include nonductile concrete or other specific types of construction. *“We would anticipate requesting \$5–7 million in supplemental funding. This, of course, does not include Stafford Act funding for disaster relief.”*

EVALUATION OF THE EXERCISES AND PARTICIPANT PERFORMANCE

Following each exercise, the facilitator evaluated the exercise. Evaluations for Exercises 1 and 2 were provided to the NEHRP agencies and EERI for their information and comment. All three evaluations are provided in the ATC final report (ATC 2005). While a number of criteria exist for evaluation of an exercise of a plan, the primary criteria for evaluation for these exercises was based on their purpose, that is, *whether or not the actions called for in the NEHRP Plan were effectively implemented during the exercise*. Other criteria for evaluation included effectiveness of the exercise (i.e., Was it realistic? Did it engage the participants?), performance of the participants, and integrity of the Plan. Based on these criteria, the evaluation of the three exercises concluded that the exercises were well structured and realistic, holding the attention of the participants for the full four hours; NEHRP agency performance, as might be expected, improved significantly between Exercises 1 and 2, and somewhat less in Exercise 3 (i.e., the “learning curve” was being climbed, and a point of diminishing returns was being reached); and the Plan itself was found to be adequate, although a number of improvements were identified as desirable to further enhance NEHRP agency response (discussed below under Lessons Learned and Recommendations). More specifically:

- **Exercise 1** was perhaps the simplest, in that it covered a relatively localized area, and involved the California Clearinghouse (which has developed its own investigations plan) and other persons experienced in investigating actual earthquakes. An interesting aspect was that the 22 December San Simeon (M_w 6.5) earthquake closely followed Exercise 1 (held on 19 December). Participants in Exercise 1 subsequently reported that Exercise 1 had been “a great help...in dealing with the earthquake” (W. Leith, personal communication).
- **Exercise 2** posed more difficulties to the participants, as it covered a broad multi-state area, and the non-NEHRP agency participants were less experienced in earthquake investigations than in Exercise 1. Exercise 2 also had several “surprises,” such as foreshocks, which realistically represented a central U.S. earthquake scenario. These confused the response of some participants, but in general

the NEHRP agency performance (which was the focus of the project) was significantly improved over Exercise 1, implementing actions in a timely manner.

- **Exercise 3** was perhaps the most complex (the exercises had been designed to be increasingly complex), involving Puerto Rico and then having the “surprise” of an eastern seaboard tsunami. The participants generally did not give the initial Puerto Rico tsunami enough consideration and were somewhat surprised when the tsunami was reported in South Carolina. Exercise 3 also extended the NEHRP Plan by incorporating a request by the President’s Science Advisor for a briefing. This is not called for in the Plan, but is quite realistic, and the NEHRP agencies did not adequately come together for the requested briefing. Overall, however, training and preparedness of the NEHRP agency personnel, and all other participants were significantly enhanced by the three exercises.

LESSONS LEARNED AND RECOMMENDATIONS

While several lessons were learned from exercising the Plan, the most important may have been the demonstration of the need to exercise the Plan in order to educate those who *must* execute the Plan. A plan describes a process for a series of actions. The exercises were a first step to make that process a part of NEHRP’s post-earthquake response. A number of practical lessons were learned from the exercises, the following among them:

- The Plan was validated by the exercises, with no major problems or omissions in the Plan being identified.
- Maintenance of the Plan is an ongoing need
- Specific NEHRP agency personnel involved in the exercises had some familiarity with the Plan prior to the exercises, and those personnel are now knowledgeable in the Plan, and in the needs and opportunities related to post-earthquake Investigations in general. Note that this capability to coordinate post-earthquake investigations has the added benefit of being almost equally applicable to other natural and technological post-event investigations. However, the NEHRP agencies in general need more formal training and exercising in the Plan.
- The electronic link employed in the exercises was new to many participants, and they found it useful. Many assumed it was a permanent feature of NEHRP, and did not realize it would not exist after the exercises ended. Virtually all participants thought a NEHRP electronic link should be created and maintained for use in actual earthquakes and perhaps other NEHRP agency business.
- The Plan stipulates that 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. This action was not adequately addressed by the agencies in the exercises, and should probably be pre-implemented, and automated, to the maximum extent possible.
- There is no plan or procedure for archiving of data collected as part of NEHRP post-earthquake investigations. This deficiency was clearly identified and the

subject of a major recommendation in the Plan (USGS 2003). The exercises emphasized this need once again.

Based on the experience of this project, the following recommendations were made:

1. **Plan Maintenance:** NEHRP agencies should meet regularly to communicate the status of each agency's NEHRP-related activities. Within the USGS a NEHRP Post-earthquake Investigations Plan Coordinator (NPIPC) should be designated who would be the Plan's "keeper," a procedural resource to the NEHRP agencies during implementation of the Plan in an actual event. The NPIPC would be responsible for maintaining the Plan, a list of candidates for the post of NEHRP Investigations Coordinator, and other Plan-related infrastructure (e.g., data archive). The NPIPC would be the Plan Coordinator, and is not to be confused with the NEHRP Investigations Coordinator for any particular post-earthquake investigation. The latter position is a temporary assignment that is filled only when the Plan is implemented.
2. **Plan Exercises:** Exercises of the Plan should occur annually, and include a process for orientation in the Plan of the NEHRP agencies and other interested parties. The NPIPC or other persons in USGS should conduct these exercises to institutionalize the Plan and the protocol for post-earthquake investigations within the agency charged with that task (i.e., USGS). Future exercises should move about the country, using regions such as the Pacific Northwest, Utah, the Northeast, and Alaska and Hawaii before returning to the regions already exercised.
3. **Communication:** A NEHRP electronic link should be created and maintained for use in actual earthquakes and perhaps other NEHRP agency business.
4. **Data:** Coordination of data collection, preservation, archiving, and dissemination should be greatly improved. Formal procedures and tools for sharing of data and information should be developed. A centralized (e.g., Web-based) data archive should be developed and maintained.

CONCLUDING REMARKS

Earthquakes are infrequent and potentially very severe events that come without warning. While lessons must be captured as opportunity permits, good preparation can maximize each learning opportunity towards the goal of reducing losses. The NEHRP Plan provides a foundation to learn from earthquakes. The exercises described above verified this and built on that foundation to significantly improve the readiness of the NEHRP agencies and a number of their state and local partners for investigating the next major earthquake. Independent of earthquakes, many other agencies are tasked with responding to various contingencies and developing response plans that need to be exercised. The information here on the processes and resources required to develop and implement plan exercises has been presented in the hope that it can serve as a resource for that purpose.

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