Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Lessons learned in the post-earthquake investigation process

S.K.Tubbesing
Earthquake Engineering Research Institute, Oakland, Calif., USA

ABSTRACT: During the past three years, EERI has conducted major post-earthquake reconnaissance investigations in Armenia, northern California, Iran, the Philippines, and Costa Rice. A discussion of major lessons that have been learned in the geosciences, engineering, and social and policy sciences will be provided. Problems deserving additional research will be noted and suggestions to improve the data gathering and dissemination process will be made.

1 INTRODUCTION

The Earthquake Engineering Research Institute has, since its inception, in 1949, conducted post-earthquake investigations for the purpose of improving the science and practice of earthquake engineering and earthquake hazard reduction.

During the past decade, EERI has systematized the collection of perishable data, in the period immediately after damaging earthquakes, under the Learning from Earthquakes program, funded by the National Science Foundation. The LFE Program has enabled researchers to travel to earthquake sites throughout the world, to record and analyze impacts to the physical and social structures. Information obtained in this manner has lead to improved building practices, code modifications, and reduced losses in subsequent earthquakes.

In many instances, field observations have identified new challenges for those concerned about improving preparedness, mitigation, response or reconstruction. By specifying new areas or problems that require additional research, reconnaissance teams have served to stimulate and diversify the research field, and improved the state of practice.

Over the years, considerable experience has been gained in the conduct of the reconnaissance process itself, making data gathering more effective. An *Earthquake Response Plan and Field Guide* (EERI, 1991) has been published, incorporating many procedural lessons, and establishing high priority data needs for future team members.

Since 1988, EERI has conducted major reconnaissance efforts in Armenia, northern California, Iran, the Philippines, and Costa Rica. Multidisciplinary investigation teams have traveled to the site of the event and prepared detailed reports. Upon return, team members have engaged in public briefings, and in some cases, video tapes and instructional slide sets have furthered the dissemination of field observations.

During this same period, several less damaging earthquakes have been studied by local research teams and more than twenty brief reports have been prepared and inserted into the EERI Newsletter, as part of an effort to reach professionals throughout the world in earthquake specialties.

This paper will draw upon these experiences to provide examples of the many valuable insights that have been gained in the geosciences and geotechncal engineering, structural engineering, architecture and urban planning, social and policy sciences, and emergency response. It will note primary areas in which additional research is called for, and discuss ways in which the post-earthquake information gathering and dissemination processes can be made more responsive, efficient, and accessible.

2 LESSONS AFFECTING PROFESSIONAL PRACTICE AND POLICIES

2.1 Geosciences and geotechnical engineering

Post-earthquake investigations of damage patterns after the Mexico, Armenia, Loma Prieta and Philippines earthquakes, and analysis of strong motion records following the Loma Prieta earthquake, emphasized the significant role played by site conditions in the amplification of ground motion (EERI 1992 forthcoming, 1989, 1990, 1991A). These observations emphasize a greater need to incorporate information on local ground conditions into design decisions.

In both the Loma Prieta and Costa Rica earthquakes reconnaissance investigators noted that extensive liquefaction and landslides caused significant damage to engineered buildings and bridges, in some cases, at relatively great distances from the earthquake rupture zone (EERI 1990 and 1991B).

2.2 Engineered Structures

The opportunity to view significant building failures before the damaged structures are demolished and removed has enabled investigators to determine precise causes of failure and to compare those structures to others that performed well in the same locations.

In Chile, researchers noted that buildings with substantial shear walls performed with minimal damage, even when the quality of construction workmanship was poor. In a number of recent events, the regular configuration of buildings played an important role in their superior performance compared to buildings with irregular configurations (EERI, 1992 forthcoming).

In Armenia, researchers noted the absence of ductile detailing, inadequate connections and eccentricities in column bars at splices, all contributing to building failure. Buildings in the same general area with highly redundant lateral force resisting systems and better inter-connections performed, on the whole, well (EERI, 1989).

2.3 Lifelines

Bridges and highway structures, gas and water pipelines all suffered significant damage in recent earthquakes. Reconnaissance investigators pointed to a combination of contributing factors including poor or variable site conditions. In the Loma Prieta earthquake, failures of the viaducts were affected by unconfined shear keys; inadequate joint steel; and variations in lateral stiffness. In Costa Rica, brige failure could be attributed to poor soils, inadequate pile lengths, and lack of redundancy (EERI, 1990 and 1991B).

In the Philippines, liquefaction significantly affected waste and water systems, ports, roads, and bridges, calling attention to the need in seismic hazard areas to catalog potential liquefaction sites and take mitigative action to densify the soil, to increase its bearing capacity in areas where critical lifelines performance must be sustained (EERI, 1991A).

2.4 Architecture and urban planning

Observations in urban areas, in California, Iran, the Philippines, and Costa Rica have drawn increasing attention to the lack of functionality experienced by businesses and industrial facilities as a result of non-structural damage. Extensive damage to expensive equipment, and lack of access to work sites, due to water damage or lack of power, contributed to large economic losses (Astaneh, 1990; EERI 1990, 1991A, and 1991B). Potential for significant loss of life and injuries in classrooms, theaters, and other common assembly areas, from the failure of a range of non-structural elements has also been underscored by recent field observations. Today, building owners are placing increasing demands on engineers to assure building functions will not be seriously disrupted following earthquakes. This presents as much of a challenge for the architect and interior designer as the engineer.

2.5 Social and policy sciences and emergency response

Dramatic building and structure collapses in Mexico, Armenia, and Loma Prieta earthquakes have emphasized the need to know more about the epidemology of the built environment. Search and rescue techniques have improved in each ensuing earthquake, but post-earthquake field observations have caused emergency managers to now place greater emphasis on training local inhabitants, who will serve as the primary and most effective rescue personnel in the immediate aftermath of an earthquake (Bertero, 1989; EERI 1989, 1990, and 1992 forthcoming).

In general, greater training and education of the public and relevant professions is critical. Attention in the past to preparing plans for immediate shelter, temporary housing, and long-term community reconstruction has been seriously inadequate. Recent large urban earthquakes have demonstrated the need for an integrated approach to building design, land use, and emergency planning in seismic hazard areas.

Following devastating losses in Armenia and other areas where soil conditions dramatically affected ground motion and liquefaction, architects and urban planners have come to acknowledge the need to work more closely with geoscientists and engineers to identify appropriate zones for redevelopment of entire cities (EERI, 1989).

3 CHANGES AND IMPROVEMENTS IN THE COLLECTION OF PERISHABLE DATA DURING POST-EARTHQUAKE INVESTIGATIONS

Systematic post-earthquake investigations in the United States have been carried out for more than four decades. Over the years, this activity has evolved, becoming more scientifically rigorous and more broadly based. In the earliest years, individual engineers sought to observe and record, through still photographs, the extent and nature of damage to structures, and infra-structure, including lifelines.

Certainly, this ad hoc, highly individual approach still occurs after every earthquake, but in order to improve the quality and reliability of observations, EERI reconnaissance team members follow data collection guidelines and data needs identified in the *Earthquake Response Plan and Field Guide*. Investigators obtain and systematically record perishable data, in various formats, including notes, photographs and slides, and video photography. Together these data provide a reliable record of earthquake impacts, that can be reviewed and analyzed at greater length at a later time.

Team members come from research and practice in each of the disciplines in the earthquake field. They work together to share insights and suggest additional areas for investigation while in the field, resulting in a more organic and complete picture of damage and loss and potential mitigative techniques.

4 ADDITIONAL RESEARCH AND RECOMMENDATIONS

For a number of years, efforts have been made to gather information where it was felt that knowledge or research was inadequate or where previous research has pointed to information gaps.

This process has recently become more formalized. Following the Mexico and Loma Prieta earthquakes, EERI brought together members of the field reconnaissance team, and others who had carried out preliminary reconnaissance investigations, to identify and rank the most needed research. Their recommendations were compiled and distributed widely throughout the United States research community in order to ensure that problems identified by the early site investigations were given adequate attention by the research community, especially by those who were not able to visit the damaged areas themselves (EERI, 1990).

Looking over the past few years, patterns begin to emerge. As increased recognition is made of the multidisciplinary nature of mitigative actions, investigators have called for greater interaction and exchange between each of the disciplines.

The following specific recommendations are provided as representative of the types of research recommendations that have emerged from post-earthquake investigations.

4.1 Geosciences and geotechnical engineering

Available strong motion records following the Loma Prieta earthquake in California provided critical information to the geoscience and geotechnical engineering communities. Efforts should be made to put such instrumentation into place and maintain it in working order in seismic hazard areas throughout the world (EERI, 1990).

4.2 Engineered Structures

In areas where building codes and local policies existed prior to the earthquake, research must be coordinated to determine the effectiveness and extent of implementation. Recently adopted damage assessment techniques need to be evaluated. Another recurrent theme that has emerged from the professional community, is the critical need to develop consistent standards for the repair and retrofit of damaged buildings. In areas where pre-earthquake strengthening has been implemented, the post-earthquake period calls for rigorous analysis of the effectiveness of the various techniques.

4.3 Lifelines

For each of the lifeline systems, a determination of precise location, extent, and cause of damages must be made, before a decision can be made as to whether to repair or relocate various lifeline systems. Structural and mechanical engineers must work together with geoscientists, urban planners, and economists to project potential losses, based on current performance of each of the lifeline systems. Ultimately, the decisions will need to incorporate data from many areas to overlay data on soil type and recurrence interval with fault locations, and capability of state-of-the-art design. Regional economic impacts for short-term and long-term system failure need to be incorporated in the final determination.

4.4 Architecture and urban planning

Analyses of regional economic impacts following the Loma Prieta earthquake demand that increasing attention be paid to potential loss of function that may occur with damage to non-structural components and contents. Greater coordination is needed in siting and development of transportation networks, critical facilities, and lifelines that affect the recovery and reconstruction of the regional economy.

4.5 Social and policy sciences, and emergency response

On-site documentation of relief efforts following damaging earthquakes has recorded repeated problems with the delivery of needed technical equipment and supplies. Often inappropriate or unneeded drugs, clothes and other materials overwhelm relief efforts.

Greater attention must be paid to developing more effective communication both within the affected area, to improve response activity, as well as with the outside area, to prevent inappropriate responses.

Policy reserchers need to work more closely with the engineering community to help determine and quantify levels of acceptable risk in order to modify existing building codes, communicate risk information more effectively to building owners, and develop appropriate guidelines for repair and retrofit standards.

5 TRAINING

As we look to the future in this Learning from Earthquakes research program, greater attention will be paid to providing formal training to prospective team members, drawing upon field expertise of veteran researchers. Training programs will focus on improving techniques in data collection, recording, measurement, and analysis. Particular attention will be given to establishing a mentor program, pairing experienced field researchers with young researchers and professionals. Efforts will be made to heighten the participation of team members from throughout the country, especially in areas of potential future seismic activity.

The research field has matured to the point where only increasingly focussed information about the effects of earthquakes will make it possible to improve existing design and construction techniques for new buildings or to strengthen existing structures so that the impact of future earthquakes will be reduced.

6 DISSEMINATION TECHNIQUES

None of the above research collection will achieve a significant reduction in losses unless the field observations are communicated to professionals working in this arena. The transmission of information captured in the field to a broader audience through various media, including public briefings, written reports, and video records have, in the past several years become integral to the communication process and to the Learning from Earthquakes program.

Public briefings provided for the professional community and policy-makers are now an accepted part of the LFE program, and are held in cities in seismic risk areas throughout the United States. These briefings, typically scheduled within a month after the team's return, provide immediate observations and suggest opportunities for further research or ways in which practice should be modified. Reporting not only on the failure, but successful performance or response techniques, team members are able to reach the most interested members of the profession in a very direct way.

For the many others, throughout the U.S. and in other countries, who are not able to personally attend the briefings, EERI has prepared annotated slide sets and in two earthquakes, Armenia and Loma Prieta, a video that contains excerpts of the actual briefings. These materials have been in heavy demand and, along with the published reconnaissance reports, issued through the EERI technical journal, *Earthquake Spectra*, continue to be sent throughout the world, years after the events themselves.

7 CONCLUSIONS

Data gathered rapidly in the first few weeks after an earthquake will be documented, analyzed, and evaluated by researchers for months and perhaps even years. In some cases, information gathered by the reconnaissance team will reinforce what is already known about geologic and tectonic processes and in many instances it may reassure engineers that current techniques seem to be working. But as a result of this Learning from Earthquakes program and other research efforts, new information will now be available to provide critical input for future siting and building decisions and for preparedness, response, and recovery planning. The research base will benefit as contributors draw attention to critical gaps in knowlege, where further basic research should be carried out.

Through the continued sharpening and improvement of the investigation process, researchers will be able to contribute their knowledge to change the built environment, and to improve preparedness, response, and reconstruction practices.

EERI is committed to continued leaderhip in post-earthquake investigations, viewing this program as a unique opportunity to transform the devastation and loss of earthquakes into an opportunity to design and build a safer future for citizens of all countries, who live with seismic risk.

REFERENCES

Astaneh, A.H. and G. Ashtiany, 1990A. "The Manjil, Iran Earthquake of June 1990." *EERI Newsletter, Vol. 24, No. 12,* El Cerrito: 5-13.

ATC/EERI, 1992 forthcoming. *Proceedings of a Workshop for Utilization of Research on Engineering and Socioeconomic Aspects of the 1985 Mexico and Chile Earthquakes.* Oakland, EERI.

Bertero, V.V., ed., 1989. *Lessons Learned from the 1985 Mexico Earthquake. Reducing Earthquake Hazards.* EERI Report 89-02.

EERI, 1989. "Armenia Earthquake Reconnaissance Report." *Earthquake Spectra Special Supplement,* August 1989.

EERI, 1990. "Loma Prieta Earthquake Reconnaissance Report." *Earthquake Spectra, Volume 6, Special Supplement.*

EERI, 1991. *Earthquake Response and Field Guide.* Learning from Earthquakes Project Report 91-A.

EERI, 1991A. "Philippines Earthquake Reconnaissance Report." *Earthquake Spectra Supplement A to Vol. 7.*

EERI, 1991B. "Costa Rica Earthquake Reconnaissance Report." *Earthquake Spectra Supplement B to Vol. 7.*