

COLLECTION & MANAGEMENT OF EARTHQUAKE DATA:

Defining Issues For An Action Plan



Recommendations from a Workshop
Sponsored by the Earthquake Engineering Research Institute
September 19th and 20th, 2002, Pasadena, CA

Collection and Management of Earthquake Data:
Defining Issues for An Action Plan

Developed by the Earthquake Engineering Research Institute
From a Workshop held in Pasadena, California
September 19th and 20th, 2002

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Steering Committee:
Mary Comerio, Chair
Nesrin Basoz
Ronald Eguchi
Marjorie Greene
William Holmes
Charles Kircher
Robert Reitherman
Charles Scawthorn
Susan Tubbesing

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Copies of this report may be ordered from:
Earthquake Engineering Research Institute
499 14th St., Suite 320
Oakland, CA 94612-1934
Telephone: 510-451-0905
Fax: 510-451-5411
e-mail: eeri@eeri.org
website: www.eeri.org

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PREFACE

On September 19th and 20th, 2002, the Earthquake Engineering Research Institute (EERI) hosted an invitational workshop with 70 experts in the fields of earthquake engineering, earth sciences, and the social and policy sciences, to identify the major issues in developing an Action Plan for an earthquake damage and loss data collection and management framework. The need for such a workshop grew out of EERI's Learning from Earthquakes Program, supported by the National Science Foundation. Under EERI's Learning from Earthquakes Program, rapid changes in information technology are allowing participants to consider electronic data collection and storage in a much more systematic manner. It was intended that workshop participants would identify an Action Plan that would define a schedule and the needed resources and steps to establish a more systematic database within the next five years. It was expected that workshop participants would make recommendations for lead agency responsibilities, clarify data collection and access issues, identify training needs, and detail maintenance and repository concerns.

However, once at the workshop it became apparent that developing such an Action Plan is more complicated process than originally thought. Workshop participants did not want to limit the discussion to post-earthquake data collection. Instead, the group (which represents a diverse range of disciplines and experience), wanted to expand the discussion to include the broad range of data needed to study and learn from earthquakes. These include pre-earthquake conditions and building inventories, post-earthquake damage assessments, human impacts, social and economic conditions before and after the event, and long term recovery issues. The group not only expanded the kind of data to be discussed, they also reviewed the time frame for data collection and the mechanisms for sharing and archiving data for future research. Given the expanded scope, this report has evolved from an "Action Plan" to a document which defines the issues for an action plan. This document lays out a broad approach to understanding earthquake data issues that should ultimately result in a much stronger and more effective set of action plans.



SUMMARY OF RECOMMENDATIONS

The earthquake community stands at a critical juncture in terms of how it learns about earthquakes. Rapid and profound changes in the technology used for data acquisition, computing and information management now allow the community to consider acquiring, analyzing and managing data in new ways. Improving the collection and management of data, immediately in post-earthquake reconnaissance as well as in long-term impact assessments, are central to improving knowledge gained from earthquakes. To help define these issues, EERI held an invitational workshop on September 19th and 20th, 2002, in Pasadena, California (see Appendix A for Workshop Agenda). Over seventy members of the broad earthquake community, representing a wide range of disciplines and skills, came together for two days of brainstorming sessions and discussion, developing preliminary recommendations that have been organized and are presented in this report. The recommendations are organized in three major categories: **Improving Data Collection, Supporting Data Access** and **Improving Data Organization and Use**. The various suggestions and ideas related to each of these three large concepts have been incorporated in the following recommendations. Because the workshop participants took a very broad approach to this topic, priorities and specific funding requirements are not attached to these recommendations. Rather, the authors urge the establishment and funding of a series of focused working groups that will tackle these issues in a more systematic manner. Recommendations in the three major categories are as follows:

1. Improve Data Collection

Develop and Fund a Strategy for Improving Collection of Damage and Loss Data

- Define the important datasets that need to be collected for each discipline.
- Create a data dictionary and data structure for the data sets, so that the academic, government and private sectors are all using the same language to describe the same concept.
- Involve social sciences expertise; these disciplines are well trained in survey design, data measurement, analysis and evaluation, and should be encouraged to play a bigger role in improving data collection generally.
- Define guidelines for each discipline for the collection process and the application of technology
- Develop and fund protocols for data collection and archiving (formats, metadata, location)
- Establish cooperative agreements, relationships and data-sharing plans in advance of an earthquake

Invest in Inventory Development

- Acquire pre-event inventory data after an earthquake
- Build inventory from existing data sets
- Establish a central location for inventory data
- Use aerial surveys
- Use scenarios to identify data needs and gaps

The Next Step in Improving Data Collection

- Involve many different disciplines and various types of data users, as well as people who generate data, in developing an overall strategy.
- Set high standards and include representation from the various disciplinary groups.
- Develop detailed work of identifying data sets, creating a data dictionary, defining data-specific guidelines by individual disciplinary groups.
- Recognize that this task is a high priority next step that is critical to further tasks in improving data collection.
- Acknowledge that significant funding will be required, most likely assembled from a combination of NEHRP agencies

2. Support Data Access

Resolve Access and Privacy Issues

- Explore options for removing personal identifiers
- Investigate options for sharing or reducing costs, increasing value of data
- Require the reporting of data where possible
- Be sensitive to special or changing circumstances

Build Constituencies for the Data

- Educate individual data providers to build broader constituency
- Increase opportunities for individual investigator participation
- Recognize the need for a government agency that conducts structural and geotechnical engineering studies
- Coordinate with existing technical organizations

The Next Step in Supporting Data Access

- Improving access to data requires a commitment of time and will, and less of financial resources.
- Encourage creative problem-solving among agencies and the research community
- Develop Memoranda of Understanding between data generators, such as local governments, to share data.
- Establish Cooperative Agreements with data generators, such as insurers and agencies including the Small Business Administration. These relationships can be tapped to gather inventory and loss data. Once agreements are established they should be tested and relationships maintained.
- Develop an inventory protocol.
- Encourage an exchange of strategies with the Network for Earthquake Engineering Simulation (NEES) program, which has begun to grapple with some of these same issues.

3. Improve Data Organization And Use

Evaluate Models for a Data Repository

- Evaluate options for repository location
- Evaluate options and make recommendations for types of data to be stored in the repository
- Evaluate options and make recommendations for data standards
- Evaluate options and make recommendations for creating a digital data catalog

Establish a Repository (Implementation)

- Evaluate options for archiving and maintenance
- Evaluate options for use of the data, including the development of guidelines
- Evaluate possible funding sources
- Develop a series of case studies to test models and implementation scheme

The Next Step in Improving Data Organization and Use

Workshop participants focused broadly on the issues in data collection and management and did not attempt, at this stage, to set priorities. The steering committee has thus recommended that the next critical step is to create targeted task forces to set priorities in four important areas:

1. **Post-earthquake damage data collection**—What data need to be collected by what disciplines?
2. **Data repository(ies)**—What are the critical first steps in creating such a repository? What are the development and policy issues associated with the first steps of implementing such a repository?
3. **Secondary data collection (such as insurance data, government statistics)**—What should be collected, who provides, who collects?
4. **Inventory data**—How can these data be incorporated into post-earthquake investigations? What are the priorities for such data?

By establishing targeted task forces for each of these topics, experts in each of these areas can participate in more in-depth discussions. These discussions should result in a set of priorities for each broad area, including identification of the responsible agencies and organizations to manage the tasks and associated funding recommendations.



INTRODUCTION

The earthquake community stands at a critical juncture in terms of how it learns about earthquakes. Rapid and profound changes in technology now allow the community to consider acquiring, analyzing and managing data in new ways. The challenges and unprecedented opportunities represented by recent revolutionary advances in data acquisition, computing and information management have been acknowledged broadly by the earthquake engineering community, most recently in EERI's consensus document proposing new research directions, *Securing Society against Catastrophic Earthquake Losses* (see EERI, 2003).

Many types of data need to be collected after earthquakes. These data are used for many purposes: informing decision makers and emergency responders in the immediate aftermath, identifying new and important lessons, calibrating models and research findings, and populating databases for future study and comparison. Among the types of data that need to be collected:

- *Geologic data* (evidence of fault rupture or displacement, liquefaction, landsliding) can disappear quickly after an earthquake yet are vital to understanding the type of earthquake that has occurred as well as to understanding the performance of buildings and infrastructure.
- Data on damage to *lifelines and infrastructure systems* (water, sewer, power, telecommunications, transportation) are important in understanding not only site-specific effects of the earthquake (breaks in pipelines, power outages, etc.) but in understanding regional implications for the economy (such as transporting goods, services, people in and out of the area).
- Data on *building damage* are used to understand the performance of certain construction materials, to understand collapse mechanisms and successful strengthening strategies, to calibrate and modify building codes and to improve future engineering practice.
- Data on *injuries and deaths* are important to understanding impacts of the earthquake on the health care system, as well as understanding effective (or ineffective) protective measures.
- Data on *emergency response procedures* are useful in understanding kinds of resources needed for response, effectiveness of search and rescue procedures, and responses to warnings and predictions.
- Data on *specific types of building losses*, such as housing losses or commercial building losses, are used to determine immediate shelter needs, effects on different population groups (low income residents of older apartment buildings, small business owners), economic impacts and implications for repair and reconstruction strategies, including changes that might be required in population densities, characteristics of the building stock and patterns of

development.

- Data on the political context of the affected area are used to determine the kinds of issues that the community may face in rebuilding (development, land use regulation, historic preservation, impact on tax base, commercial redevelopment) and the ability of the community to resolve such issues.

For an even more complete discussion of the value and importance of the different kinds of data that are collected after an earthquake, refer to EERI's *Post-Earthquake Investigation Field Guide* (EERI 1996).

Key to improving lessons from earthquakes is the need to take advantage of advances in information technology to improve the collection and management of data. Technology now provides tools that make the process more systematic and rigorous. Previous studies have documented the need to approach information acquisition and management in a more systematic manner: See, for example, a study by the National Research Council, proposing a framework for loss estimation (National Research Council 1999), and the newly released NEHRP Post-Earthquake Coordination Plan, calling for a process to formalize data management and archiving (Holzer et. al. 2003). *Securing Society Against Catastrophic Earthquake Losses* notes that:

The ability to acquire knowledge and insight from vast amounts of data is transforming numerous scientific and engineering disciplines. The opportunities in earthquake engineering for information management include fusion of data from sensors with models, data mining, large-scale data repositories, and significantly improving the flow of information for decision-making and emergency response and management. Managing data on this scale will be very challenging, requiring many advances in data analysis, data management, and the merging of information from diverse sources (EERI 2003).

Following the 1994 earthquake in Northridge, California, major research efforts were undertaken not only by academic institutions, but by various government agencies, private insurers and independent organizations. The largest U.S. earthquake in terms of damage, this earthquake was also the first U.S. earthquake where Geographic Information Systems (GIS) were used in an effort to collect data more systematically. The earthquake generated an unprecedented amount of research. And yet, at a workshop convened to summarize post-earthquake research, almost every disciplinary group identified missed research opportunities from lack of data (CUREE 1998). Several examples of missed opportunities identified by workshop participants included:

- Limited number of free-field recording stations restricted the understanding of structural performance as well as near-field effects (p. I-54)
- Understanding of response also restricted by the limited number of motion observations in monitored structures (p. I-54)
- Opportunities to evaluate structural response to reasonably large ground motions missed by limited instrumentation of large structures (p. I-62)
- Documentation of the type and cause of the failure of building piping systems was not made (p. I-59)
- Documentation was not made of needed procedures and software to facilitate the collection, cataloging, and evaluation of emergency response, damage and recovery and restoration statistics and costs highlighted by the earthquake (p. I-64)

- Detailed assessments were not made of how various technologies were used in responding to the earthquake and whether they actually made a difference (p. I-68)
- Very little hard data were collected on the direct or indirect business impact of disasters, thus missing the opportunity to understand effects on businesses and their ability to recover (p. I-66)

As part of its Learning from Earthquakes Program, EERI has the task of developing an Action Plan for Loss and Damage Data Protocols, directed to the NEHRP agencies. This plan will build from the types of data deficiencies identified after Northridge, with the hope that in future earthquakes, with more attention focused on how to capture and manage data, there will be fewer lost opportunities. This report is the first step in developing such a plan, identifying issues, needed next steps and direction for targeted task forces to address specific issues.

Improving the collection of, access to, and management of data, in post-earthquake reconnaissance as well as in long-term impact assessments (which require pre-inventory data and secondary source data), are central to improving knowledge gained from earthquakes. As noted in the Survey of Surveys (Appendix D), there is a diverse range of earthquake data that have been and are currently collected, ranging from seismic sources and ground-motion time histories to economic losses. Workshop participants identified the following problems with current data collection:

- **Lack of coordination:** After earthquakes, multiple teams are in the field, performing reconnaissance and/or research. These teams may not be well coordinated, collecting the same data, and overlooking other critical and perishable data.
- **Perishable data:** Some of the data that need to be collected are extremely perishable. With little coordination and/or access, these data sometimes disappear before they can be collected.
- **Lack of training and experience:** In the immediate aftermath of an earthquake there are typically many researchers and earthquake professionals in the field, with differing levels of experience and training. They may be unfamiliar with the necessity for collecting certain data, or with data collection procedures, resulting in poor or unusable data.
- **Lack of repositories:** Data that are collected are often stored by individual researchers and field investigators, making access by others difficult. Some disciplines are doing a better job of organizing themselves to archive data in a central repository, such as the earth scientists and COSMOS¹. Other disciplines have data scattered in various locations. There are also important questions about the kinds of data that should be stored, who should have access, how the data are archived and/or updated, etc.
- **Different time frames for data collection:** Different types of data need to be collected at different time periods before and after an earthquake. Some data are impossible to collect in the first few days after an earthquake, including accurate direct and indirect costs of the earthquake, complete damage surveys, extent of lifelines disruption, and rebuilding and reconstruction policies. Inventory data are, by definition, collected prior to an event. These different time frames mean that different tools are necessary for accessing and storing data.
- **Data maintenance:** Issues of maintenance and access were seen as important questions by workshop participants.
- **Data linkages:** Connections between data sets are an important issue that can become more problematic over time. This includes issues of data standardization and compatibility, as well as how to handle data that become outdated or change over time.

This document addresses many of these problems, by proposing improvements in the three major areas:

data collection, data access, and data organization and use.

Background

The workshop opened with a series of presentations that provided the background for discussions that took place over the next day and a half. These presentations summarized existing efforts that provide the context for the issues presented here.

Learning from Earthquakes: A Survey of Surveys

Keith Porter, a senior research fellow at the California Institute of Technology, summarized the major recommendations from the white paper he prepared as background to the workshop (see Appendix D for the complete paper). The white paper documents existing data collection procedures and resources, and recommendations from researchers for improvements. Data collection currently exists in the following categories:

- General reconnaissance (overview information of earthquake damage)
- Waveforms and location of earthquake
- Subjective intensity (did you feel the earthquake?)
- Site conditions
- Existing buildings
- Safety inspections (more detailed information on building performance)
- Building-specific performance (ATC-38)—six page survey form
- Nonstructural components
- Lifelines
- Socioeconomic impacts

Porter described the few existing efforts to aggregate survey data into a larger database, particularly efforts after the Northridge earthquake. These conclusions presented in the white paper, served as background to further discussions at the workshop:

- Many data protocols already exist (for reconnaissance, emergency preparedness and recovery, etc.)
- The protocols are mostly nonstandard formats with short-lived data, making long-term research difficult
- New technologies provide opportunities to improve data collection, archiving and dissemination, the standard ontology of earthquake data, and the utility of data for a variety of users.

The NEHRP Post-Earthquake Coordination Plan

Tom Holzer of the United States Geological Survey (USGS) summarized a recent activity to develop a framework to coordinate the post-earthquake investigations of the National Earthquake Hazards Reduction Program (NEHRP) agencies. This plan, which has just been released by the USGS (see Holzer et. al 2003), documents the role of each of the primary NEHRP agencies for the initial five years after an earthquake—during Phase I (reconnaissance); Phase II (the collection of perishable data); and Phase III (data collection, research and development). The plan attempts to address the major deficiencies of post-earthquake investigations, identified as inadequate breadth of coverage of data (NEHRP agencies do not collect structural and nonstructural

damage data; inadequate use of information technology tools; inadequate data management; and inadequate funding. The NEHRP plan proposes a solution to improve damage surveys:

- Standardize protocols (building on existing formats)
- Identify collectors (use knowledgeable collectors)
- Archive data (use the Network for Earthquake Engineering Simulation--NEES²)
- Compile compatible inventories (use HAZUS users groups³)

The plan also recognizes that special, dedicated funding is needed to support post-earthquake investigations.

Earthquake Damage and Loss Data Needs

Charles Scawthorn, an earthquake engineer in private practice, presented his view on what is needed to improve the documentation and dissemination of earthquake data. He noted that much of the data that are currently collected after earthquakes are being lost, with the exception of earth science data that are collected and archived by the USGS. He gave several startling examples of data that have been lost, including a survey of 12,000 residential buildings after the 1971 San Fernando earthquake that appears to be missing. Scawthorn pointed out that in the U.S. there is a national earth sciences agency, but no compatible built environment or social sciences agency, which could collect and maintain those data.

Scawthorn recommended the development of a “National Earthquake Experience Database (NEED)” that would significantly enhance research, by making larger, cross-event, datasets available, and would help identify data gaps and research needs.

Additional Background

There were two additional presentations the first day of the workshop to provide background for the discussions:

Use of New Technologies in Field Reconnaissance

Use of technology for data collection has been embraced in many other industries. Paul Deshler of Accela, Inc. described a project being carried out with EERI. Accela, a company that has developed building inspection forms for various local governments for use with handheld personal digital assistants, will be developing field reconnaissance forms for EERI on handheld devices that can then be uploaded and stored in a web-based database. The forms will be adapted from forms currently available in EERI’s *Post-Earthquake Investigation Field Guide* and on EERI’s web site. Where possible, forms will be tied to spatial identifiers (latitude and longitude) in order to map the survey results in a Geographic Information System (GIS) possibly in near-real time. Other electronic files, including documents and photographs can also be linked to the forms with a geographic identifier. Forms can also be completed on laptop computers, or even desktop computers after returning from the field, and then uploaded to the database developed for that earthquake. This is a first step towards more systematic data collection and rapid dissemination of information from the field.

Post-Earthquake Damage Assessment in Italy

During the luncheon, Agostino Goretti of the Italian National Seismic Survey made a presentation on Italy’s efforts to collect data systematically. Italy has a long history of collecting data after earthquakes, and Goretti discussed some of the issues that have changed over time, as well as current challenges facing the Italians in developing a standardized procedure and training program.

Carefully identifying the purpose of the damage survey, using GIS and pre-event databases to speed up the assessment and validation, using unambiguous terms in the forms, and insuring that inspectors are well-trained were among the primary issues he discussed. (See Appendix E for the complete paper, *An Overview of Post-Earthquake Damage Assessment in Italy*.)

From Workshop to Defining Issues for an Action Plan

Building on the three keynote presentations and the additional background information, workshop participants made a series of recommendations that have been organized into three categories: **Improving Data Collection, Supporting Data Access** and **Improving Data Organization and Use**. The various suggestions and ideas related to each of these three large concepts that emerged at the workshop have been incorporated in the discussion on the following pages.



Section I

IMPROVE DATA COLLECTION

A number of basic issues were identified at the workshop that would help improve our ability to collect data after earthquakes, including developing an overall strategy (including defining datasets, developing guidelines for the collection process and the application of technology, and developing protocols for data archiving), resolving access and privacy issues, investing in inventory development, particularly to help interpret post-earthquake statistics, and building a constituency for the data, so that individuals and organizations see value in the data that are collected and managed. Each of these issues is described in more detail below:



I. A. Develop and Fund a Strategy for Improving Collection of Damage and Loss Data

Identifying the kinds of data that should be collected and archived to further our understanding of earthquakes is a major effort, and an important first step in improving data collection. New technologies allow us to be much more systematic in our approach to data collection. There are many different data types including data, that to be most useful, need to be collected and archived prior to an event. Technology to collect data is changing rapidly and can affect the types of data that can be collected (including remote sensing, satellite imagery, use of personal digital assistants or laptop computers for immediate systematic data collection).

In discussing the kinds of protocols that could be necessary, workshop attendees identified different *types* of protocols:

Identification protocols—what kinds of data, including statistical, graphical, audio, ethnographic, etc.?

Collection protocols—the best ways to collect the various types of data, including standardized forms, interview protocols, sketches, images, etc. Templates that can be used with handheld devices or laptop computers will also be appropriate for many of the research disciplines.

Document protocols—how will data be aggregated or integrated and interpreted?

Dissemination protocols—what format will data be distributed in, who has access?

Timeline—when will data be needed or most useful?

In thinking through some of these protocol issues, it is useful to ask what is the goal of data

collection. Who will be using the data? Why are the data being collected? Many types of users of the data were identified, from those who need disaster intelligence during the emergency response to loss estimation modelers, using data to project damage and loss in a future event. Data users fall into two general categories—those who want case study, detailed information on a particular event and those who need larger data sets for analysis.

Three basic post-earthquake survey types were identified:

- An initial, broad brush, umbrella survey to identify “the big picture”—major areas of damage, issues that might require further analysis, etc. This has traditionally been the model followed in post-earthquake reconnaissance. A major limitation with this approach is that it relies on volunteers and/or researchers who collect data only on the topics that interest them. It has not traditionally been systematic, although the possibilities for systematic data collection have greatly increased with advances in various computer technologies.
- Broad interdisciplinary survey—Here, a rapid, systematic survey is required with the minimum amount of information in the quickest time possible to serve the most users. Observations should be disseminated rapidly. Primary data should be moved to a repository quickly so others can use them. Primary data from different types of users should be linked together in a meaningful way, to provide early insights into the disaster. If these data are to be collected systematically, it will probably be necessary to invest resources in the data collection efforts.
- Detailed surveys which can be used in disciplinary-specific studies, including at a minimum several types of long-term assessments:
 - An **economic assessment**, detailing the local, regional and national economic changes caused by the earthquake.
 - A **societal assessment**, detailing long-term effects of the earthquake on various groups in the population.
 - Calibration of risk models**, allowing researchers to check the validity of their models against field data.

Securing Society Against Catastrophic Earthquake Losses notes some of the issues in data collection, specifically during the emergency response phase:

After a major disaster, information and data from a variety of sources will begin to fill emergency operations centers (EOCs) and other centers involved with the response effort. These data will generally be disparate in form, quality and comprehensiveness, and will arrive at these centers at different times during the disaster. New data fusion methodologies must be developed that will help to merge and integrate these data so that more intelligent decisions regarding response can be made. Techniques that recognize the common information between these disparate data sets – particularly as they pertain to specific incidents – can be useful in validating the reliability of events requiring some type of response. In past disasters, this lack of validation has led to delayed or impeded response. In addition, technologies that help to convert or translate voice messages into text can be extremely useful in capturing the scope and magnitude of an event in real-time. When integrated with Geographic Information Systems (GIS), this type of technology can be extremely effective (EERI 2003).

Clearly, in order to successfully improve data collection, a major, funded effort needs to be undertaken that will involve all the various disciplines associated with earthquake reconnaissance and earthquake engineering in identifying the new protocols. Workshop participants recommended that a working group for each discipline involved in earthquake studies be established, using a three-pronged strategy to improve data collection protocols. The three-pronged approach includes the following three major steps:

► **I. A. a. Define data to be collected**

Define the important datasets that need to be collected for each discipline. Workshop participants identified some resources that could be built on, such as EERI's *Post-Earthquake Field Reconnaissance Guide*, and specific manuals that have been prepared by different disciplines, such as the Technical Council on Lifelines Earthquake Engineering (TCLÉE) Lifelines manual.

A special note should be made here that a more standardized approach still needs to accommodate non-standardized data-gathering, such as anecdotal reconnaissance, interviews with survivors, public policy debates, etc. By looking for such “non-standard” data, researchers may more readily discover the unusual aspects of a particular earthquake.

Workshop participants also identified a need to have better ground motion data in population centers, where most of the buildings are. This sort of preparation is invaluable when an event occurs.

Nonstructural and contents damage data have received inadequate attention in the past. Protocols need to be developed to assist field researchers collect useful data for these categories specifically.

Indirect damage, including fire and debris, as well as economic loss data, need to be addressed with specific protocols. Often these data are missing, yet they are essential to providing a clear picture of the real losses associated with an earthquake.

► **I. A. b. Create a data dictionary and data structure for the data sets**

Definitions of data, fields used for data collection, etc., should be developed and widely distributed so that the academic, government and private sectors are all using the same language to describe the same concept. For example, find a commonly accepted definition for a term such as “moderate damage,” which can be different for a bridge than it is for a building or a telecommunication tower. Part of what is needed is a set of clear, agreed-upon concepts. All data elements need to be defined via a data dictionary and precise directions. Where it is difficult to have one precise, commonly agreed upon definition, use a layered approach to information gathering. Ask more detailed questions, that when answered, can provide the desired parameter. Make forms appropriately detailed or expandable, so that a user can “drill down” into the data for more and more detail. An important step in developing the data dictionary should be to gather input from independent subject-specific experts who will agree on definitions and layering. Fields should have standard attributes, but flexible enough to account for new information types.

► **I. A. c. Involve social sciences expertise**

The social science community is well trained in survey design, data measurement, analysis, and evaluation,

and should be encouraged to play a bigger role in improving data collection generally. They could provide technical assistance to any of the disciplinary groups. Workshop participants pointed out that individual disciplines in the social sciences have specific skills that could be valuable in improving data collection, including economics, political science, sociology, history, anthropology, etc. Additionally, the library and information sciences have valuable skills and expertise that would strengthen data collection efforts.

► **I. A. d. Define guidelines for the collection process and the application of technology**

Each discipline, represented by a working group or coalition, needs to address how best data can be collected for that discipline, and the appropriate technologies that can help in data collection. Some disciplines have begun to address these issues—the geotechnical community, for example, has a current project to identify how to link web-based data. With funding from the National Science Foundation, researchers are developing a pilot web-based system linking PG&E, Caltrans, California Geological Survey and USGS example geotechnical data sets. The long-term objective (a future project not yet funded) is to extend the pilot system and develop a web-based system linking multiple data sets, capable of serving the broad needs of practicing geotechnical and earthquake hazards professionals for efficient access to geotechnical data (the COSMOS-PEER lifelines project described at <http://www.cosmos-eq.org>).

A general guideline that applies to each discipline is to use spatial identifiers. With new technologies such as Global Positioning Systems (GPS) it is possible for most data to have spatial identifiers (latitude and longitude), so that the data can then be displayed in a GIS (map-based) format. For example, for digital photos, not only record the time, but also include the latitude and longitude, which allows a user to plot the photo on a map later. There are at least three levels of spatially collected data that are useful: the GPS coordinates, an address, or a census block.

► **I. A. e. Develop and fund protocols for data collection and archiving (formats, metadata, location)**

Workshop participants identified a number of issues and recommendations that are important in developing and funding the protocols for data collection, including the need to build from existing protocols. As discussed above, protocols are needed for the identification of data; the collection of data; documentation; dissemination and a timeline for how data can be accessed and used. Some data protocols already exist and researchers and users of such data are not in a position to change the definitions or protocols. Examples include ATC-20 protocols for building safety evaluations, and insurance loss databases, where definitions have precise meanings. Identify and build from these protocols.

Protocols also need to be developed to address how the many various disciplines and communities interested in earthquakes can work together when an event occurs. These protocols will help reduce duplication and allow the research community to focus on the bigger questions associated with the earthquake. For example, funding agencies could serve a leading role by requiring multidisciplinary participation in certain types of funded data gathering efforts. If, for example, an engineering team were to include a cost estimator when observing and reporting on damage, their

report might contain useful information on cost aspects of the repair of damage, something that is important to understand but is often left out entirely from engineering studies of damaged buildings.

A further way to improve protocols is to invest more extensively in multiphased reconnaissance. Multidisciplinary reconnaissance teams should be sent out at more than one point in time to collect data and lessons from damaging earthquakes. Important lessons and data regarding economic losses or system disruptions are not available in the first weeks after an earthquake. In addition, important lessons and data for recovery and reconstruction may not emerge for months after an earthquake, and yet are critical to our complete understanding of the effects of an earthquake. EERI has two programs that begin to support such longer-term reconnaissance: Beyond Reconnaissance Grants that can be awarded immediately after a major, damaging earthquake to support more in-depth research; and Lessons Learned over Time grants that can support researchers to go back and investigate lessons that have emerged. However, both these programs are small, with very modest funding. The NEHRP funding agencies should be encouraged to support routinely such multiphased reconnaissance.

Protocols should also identify who collects the data. It matters who gathers the data and what their qualifications are. Protocols should include qualifications, and personal identification of data-gatherers. For example, a bridge expert should not be expected to gather detailed information on electrical outages, and engineers should work with public health experts when tabulating casualty data.

Related to the issue of who collects the data is the possible need for an agency with appropriate authority to require certain data collection. For example, insurance data, which might be used to provide important insights into earthquake losses, is not collected systematically enough to be reliable across states and earthquake events. In some states research data have not been collected at all; in other states the data are available only in formats that are not particularly useful for research (aggregated at zip code level; lacking information on details of construction, etc.) Also, insured properties may not represent a clear picture of the built environment; for example, in the current California political environment less than 18% of homeowners have insurance. It may be that a federal program is needed, with the authority to collect the appropriate research data, in much the same manner that Census data are collected. Perhaps an agency such as the U.S. Department of Housing and Urban Development would be an appropriate agency to oversee such data collection.

A separate yet critical issue in data collection is the need to identify funding sources. In order to have first-rate data sets, there needs to be sufficient funding for first-rate data gathering. Some important data cannot rely on volunteer or hit-or-miss efforts.

In addition, in order to get researchers and field investigators to coordinate their data gathering efforts, it might be important to provide incentives. For example, any funding agency should *require* the posting of funded research data, as a mandatory requirement of a grant.

In addition, workshop participants identified a number of specific challenges that must be addressed in the development of systematic protocols and collection methodologies:

Evolving data. Anticipate that data can change over time, and that it can take some time before

some data are reliably collected. For example, repair costs cannot be estimated two days after an earthquake. Protocols should include an appropriate time at which certain data items can be collected and should require keeping track of data history. For example, protocols need to reflect how construction costs and other costs change, and how inventory changes affect “present-value” losses.

Issues of metadata also need to be resolved. Metadata (the data that describes data or resources that can be used to help support a wide range of operations) needs to be clearly articulated in the design of any kind of repository. What standards and formats for metadata should be used? The possibilities for building on the structure provided by the Federal Geographic Data Committee (see <http://www.fgdc.gov/>) should be explored.

► **I. A. f. Establish cooperative agreements**

Many individual groups collect data, without an overview plan. There is little cooperation or coordination. Relationships and data-sharing plans should be developed in advance with insurers, the Small Business Administration, FEMA, departments of public works, etc., specifically to share inspection data, including safety and habitability data and damage data (aggregated to some agreed-upon level to address privacy concerns.) Pursue others for inclusion. The process of creating such agreements will be an opportunity to educate about the importance of such data collection, and can contribute to building a broader constituency.

I. B. Invest in Inventory Development

In order to understand the true effect of an earthquake on a building, a system or a community, we need to understand what existed prior to the earthquake. This is sometimes referred to as the denominator or the baseline measurement. Current earthquake reconnaissance and research projects that emerge from reconnaissance are often missing this element, reducing our ability to understand what really happened in the earthquake. A twenty percent system failure, for example, is only meaningful if one understands what was in the system to begin with.

To understand the denominator, inventories of pre-event data need to be collected, along with other baseline information that could help form an accurate picture of the earthquake’s effects on the physical, social and built environments.

► **I. B. a. Acquire pre-event inventory data after an earthquake**

Workshop participants advocated that a method needs to be developed for acquiring pre-event inventory data after an earthquake, as well as assembling some inventory data prior to an event. The data available and the methods that could be used to acquire them will of course vary from earthquake to earthquake. Earthquakes in developing countries present particular data challenges, since often the kind of inventory data that researchers are interested in are not available. In general, however, field investigators would benefit from background knowledge of sites examined. Maps, inventory and site soil conditions should be available in the field. When an event occurs, it is important to know which buildings have good pre-event backgrounds so engineers can be sure

to assess those for maximum learning. Examples of needed data include blueprints, soil borings, retrofit histories, published articles/studies of special buildings and lifelines. It would improve data collection to have immediate access to this information in the field.

▶ **I. B. b. Build inventory from existing data sets**

A pre-earthquake inventory of the built environment could be developed, building from existing data sets. For example, wider use of FEMA 154 (*Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*) should be encouraged. The compilation of existing HAZUS inventories could be facilitated, as well as encouraging those local communities that have not yet compiled inventory data to complete such data collection. While FEMA has invested millions in the development of HAZUS software, there has not been as significant an investment in educating users regarding the value of this model. If, through better training and implementation, FEMA could get a bigger constituency for HAZUS, this would also broaden the constituency for better inventory and post-earthquake data. Right now the HAZUS model in most communities runs on default data; there would be increased pressure for better data if users were convinced of the value of HAZUS. The Disaster Mitigation Act of 2000 might be such a tool that could be used to encourage communities to prepare and share inventories that could then be mined for relevant data after the next earthquake. Another tool that might encourage communities to prepare and share inventories is FEMA's Multi-Hazard Mapping Initiative (MMI at <http://www.hazardmaps.gov/>), which is also tied to the Federal Geographic Data Committee (FGDC).

▶ **I. B. c. Establish central location for inventory data**

To better integrate data in the future and understand the range of data sets that exist, it would be helpful to have some kind of a central location for inventory data. This repository could be either virtual, or at a particular location. The concept is discussed more completely in Section III.

▶ **I. B. d. Use aerial surveys**

Aerial surveys can also play a bigger role in pre-earthquake data collection, to establish a baseline that can then be compared against the post-earthquake environment. For example, pre-event snapshots then post-event satellite and fly-over surveys would be useful for initial reconnaissance as well as later assessment of overall extent of effects.

▶ **I. B. e. Use scenarios to identify data needs and gaps**

A scenario approach could be used to better specify information and data needs. This technique could be used to try and collect inventory data from a number of different sectors, including transportation, building stock, etc. A scenario could be created to figure out how to collect the inventory data, basically as a test to see how feasible such data collection is, perhaps in several types of communities (a data-rich community in California, for example, and a community with less inventory data elsewhere in the U.S.). A set of guidelines could then be prepared, summarizing how to collect inventory data, and how the data could be used and combined. There would also be

particular data inventory needs and issues in an international earthquake that would be need to be addressed separately.



I. C. The Next Step

It is important to emphasize here that this task—to develop an overall strategy by defining datasets, defining guidelines and developing protocols—is a major effort that will require a significant investment in terms of funding and time:

- Involve many different disciplines and various types of data users as well as people who generate data in developing an overall strategy.
- Set standards at a fairly high level, including representation from the various disciplinary groups.
- Develop detailed work of identifying data sets, creating a data dictionary, defining data-specific guidelines by individual disciplinary groups.
- Recognize that this task is a high priority next step that is critical to further tasks in improving data collection.
- Acknowledge that significant funding will be required, most likely assembled from a combination of NEHRP agencies.



Section II

SUPPORT DATA ACCESS

Critical to understanding and interpreting data is gaining access to the data, so that meaningful analysis and interpretation can take place. Major stumbling blocks to such access exist in terms of the national privacy act as well as resources that might be necessary to allow researchers access to data sets. The field data that are collected need to be shared in a systematic manner. The U.S. Geological Survey shares earth science data broadly, but there is no mechanism in some of the other disciplines for such organized sharing. In addition, not all data are collected during field investigations in the immediate aftermath of an earthquake (for example, some secondary data could be collected from government statistics, or compiled later from insurance data, etc.); however it is still helpful for the research community to gain access to such data.



II. A. Resolve Access and Privacy Issues

A major issue with gaining access to important damage and loss data after earthquakes is the proprietary and sensitive nature of the data. For example, utility companies, local governments, insurance companies, federal relief agencies all collect data about individuals, building damage, and loss data that are covered by the Privacy Act and cannot be readily accessed by the research community. These data can include information on particular buildings with individual owners as well as government program data, such as services provided to disaster victims. Both primary and secondary data can be considered confidential, and therefore off-limits to researchers. In the post 9-11 environment it was also suggested that security and access have become more important concerns, and that future access could be restricted completely for certain types of data (for example, utility infrastructure or large government structures). There was general agreement at the workshop that this is a serious concern in improving data collection and management, hence research, and one that may not be easily resolved.

▶ II. A. a. Explore options for removing personal identifiers

A major stumbling block to some data generators in considering release of data is the issue of personal identification of the data (data tied to an individual name or address). There was consensus among workshop attendees, however, that such personal information is not necessary or relevant for research and could be stripped from data sets. Some disciplines would find aggregated data as useful

as more individual data, and would therefore welcome access to aggregated data sets.

Workshop attendees discussed possible levels of aggregation that would be useful. Census tracks often change from one census to the next, making it difficult to compare data across time if it is aggregated at the track level. However, if the information could be aggregated at the block level, these geographic units do not change as frequently. The group also discussed a particularly innovative initiative after the Nisqually earthquake by FEMA GIS staff to provide data to the 100-meter grid level. This initiative has been approved by FEMA's general counsel, and should therefore set a precedent for future earthquakes, at least as far as data generated by FEMA. The 100-meter grid level could be useful for loss data and model validation⁴.

For some disciplines and some research questions, however, the data really need to be available at a site-specific or individual-specific level. For example, investigations into causes of injuries and deaths need to know the buildings in which deaths and injuries occurred. Names are almost never necessary in such research, and could certainly be stripped out of data sets. However, there are still major issues related to the Privacy Act that would need to be resolved in order for researchers to gain access to data at such a specific level.

► **II. A. b. Investigate options for sharing or reducing costs, increasing value of data**

An important issue in working with data generators, particularly public agencies or large organizations such as utilities, is cost. Public entities typically do not have the staff to provide research data, or to transform data into a format that makes it useful to researchers. The research community needs to recognize these direct costs, and develop strategies that address them, such as building funds for data transfer into research proposals.

One way to improve the possibilities for access to data is to develop strong relationships and protocols between the research community and the data generators (institutional and lifelines owners, government agencies, insurers, etc.). Mutual understanding of the important lessons that can be gained from earthquake data by researchers and data owners will create an environment where data sharing will be more possible. Data owners may be more likely to release data to researchers, at least in an aggregated form. Protocols could be developed in advance for getting access to data. The NEHRP agencies could oversee the development of such protocols.

► **II. A. c. Require the reporting of data where possible**

Another possibility of improving access is to tie the reporting of damage data to reimbursement. Local, state and federal agencies that reimburse individuals, organizations and jurisdictions for response or damage expenses, could require detailed reporting of damage from recipients of relief funds. Even in an aggregated form, these data could be very helpful in gaining a more accurate understanding of damage caused by an earthquake.

In addition, it might be possible to require NEHRP agencies to make data available to the research community. As agencies leading the national earthquake risk reduction program, the

federal agencies in NEHRP should be willing to make data they collect available to researchers, both in universities and in the private sector (at least aggregated data), and they should require projects that they fund to include a data storage and access component. They should be encouraged to develop standard procedures for publishing and allowing access, prior to the next earthquake.

▶ **II. A. d. Be sensitive to special or changing circumstances**

Workshop participants stressed that outside the United States it can be very difficult to gain access to both damage and inventory data. Relationships with colleagues and institutions in other countries need to be developed prior to the next earthquake to help facilitate such access. Certain international organizations, such as the International Red Cross, may play very helpful roles in gaining access, and perhaps in organizing the collection of certain types of data. (It should be noted that to be most effective, such access should be reciprocal, so that in a U.S. earthquake, foreign researchers and colleagues would be given access to U.S. data sets.)

Increased security concerns, post-9/11, will also most likely affect post-earthquake access. Access that has been granted in previous earthquakes to damaged buildings, areas of a city or lifeline systems may now be restricted. The nationality of earthquake investigators may be an issue; students from Middle Eastern countries, for example, will not be allowed into sensitive public buildings, or may not be allowed to investigate utility systems, etc. One strategy proposed by workshop participants is to pre-qualify investigators for certain private buildings or systems. Designated investigators could have background checks performed in advance. Access to raw data may become more problematic.



II. B. Build Constituencies for the Data

Data that can help us understand what has happened in an earthquake include information on conditions prior to an event (to help establish a baseline or denominator for interpreting damage and losses), as well as data describing damage and losses associated with an earthquake. Helping agencies and organizations understand the value of the various types of data needed is an overarching recommendation of this report. Who will collect the data? Why are the data needed? What will the data tell us? When are the data needed? These are all important questions that will frame the action plan as it is developed. Individuals, organizations and communities need to see value in the data in order to invest in their more systematic collection and management.

Pre-event data are critical to understanding what has happened in an earthquake. Sometimes organizations (government, utilities, large institutions) are not aware that their baseline data are needed in order to accurately interpret what has happened in an earthquake. And, these organizations may not be aware of the importance of such lessons. As the earthquake community, we need to take the time now, prior to the next major earthquake, to build this constituency. The workshop participants identified a number of suggestions for how this constituency could be strengthened:

▶ **II. B. a. Educate individual data providers to build broader constituency**

The earthquake community needs discussion and consensus about what is really needed in terms of data, and then individuals need to meet with various data providers (government, lifelines, etc.) about the benefits of collecting and providing these data.

One strategy for building a wider constituency for pre- and post-earthquake data is to reach out to other disciplines and communities, exchanging lessons from other types of disasters and disciplines, showing that earthquake engineering has lessons for society more broadly. The earthquake community needs to do a better job of showing our earthquake engineering contributes to safer communities generally, reducing losses and increasing sustainability.

In order to convince elected officials and decision makers in government and private organizations of the urgency and need to learn from damaging earthquakes, a program could be established to get them to the disaster site. Such decision makers could either accompany a reconnaissance team, or participate in a trip that is organized primarily as a policy education trip for them. Observing the damage and disruption firsthand that an earthquake causes makes a compelling argument for damage and loss data are important.

In addition, by participating in the earthquake clearinghouse (to be set up after future earthquakes as a coordination point for researchers), the research community is positioned to provide intelligence and to help in the interpretation of incoming data during the emergency response phase. The clearinghouse is initially intended to provide information back to offices of emergency services, however researchers might also play useful roles in individual organizations, such as utilities or hospitals. By providing needed intelligence, researchers should be able to demonstrate the value of various kinds of data.

▶ **II. B. b. Increase opportunities for individual investigator participation**

By providing more opportunities for individual learning, particularly in post-earthquake reconnaissance, a broader constituency for collecting and managing data will be developed. Students and younger professionals need to be encouraged to participate actively in data collection and field reconnaissance.

Currently EERI manages the Learning from Earthquakes Program for the National Science Foundation and has made plans to include student and young professional positions on future reconnaissance teams. However, this provides only limited opportunities. A more systematic, funded program needs to be developed to regularly support groups of students and young professionals.

▶ **II. B. c. Recognize the need for a government agency that conducts structural and geotechnical engineering studies**

At the federal level there is the U.S. Geological Survey, addressing geologic and seismological aspects of earthquakes, with responsibility to capture such data and disseminate their findings widely (see Holzer et. al. 2003). However, there is currently no equivalent umbrella agency for

structural and geotechnical engineering. While a new agency might be ideal, it is unrealistic. It could be that NIST (a NEHRP agency) could play a larger role in improving coordination among the various research activities, and insuring more complete coverage of important research issues.

▶ **II. B. d. Coordinate with existing technical organizations**

Many of the technical organizations involved in earthquake investigations could be strong partners in developing protocols for data collection and management, and are themselves often the source of such data. Such organizations include many of the professional associations, such as the American Society of Civil Engineers, the Geological Society of America, Building Officials associations, Structural Engineering associations, the American Planning Association, the National Trust for Historic Preservation, as well as various federal, state and local agencies including FEMA, the Federal Highway Administration, Caltrans, state and local offices of emergency services, regional and local planning associations, etc.

An example of a successful partnering effort emerged after the Northridge earthquake. There, the City of Los Angeles Department of Building and Safety partnered with the Structural Engineers Association of Southern California to create the Northridge Earthquake Building Damage Task Force. That Task Force was organized into subcommittees focusing on particular building types that had been damaged, such as unreinforced masonry, concrete parking structures, wood frame buildings and steel buildings. The collaborative effort worked very well, resulting in very good data that were then used to modify subsequent editions of major building codes.



II. C. The Next Step

The next step relates primarily to the idea that there needs to be more coordination and better communication among individuals and organizations currently involved in pre- and post-earthquake data collection, and with individuals and agencies who generate data of use to the earthquake research community:

- Improving access to data requires a commitment of time and will, and less of financial resources.
- Encourage creative problem-solving among agencies and the research community
- Develop Memoranda of Understanding between data generators, such as local governments, to share data.
- Establish Cooperative agreements with data generators such as insurers and agencies such as the Small Business Administration. These relationships can be tapped to gather inventory and loss data. Once agreements are established they should be tested and relationships maintained.
- Develop an inventory protocol.
- Encourage an exchange of strategies with the National Earthquake Engineering Simulation (NEES) program, which has begun to grapple with some of these same issues.



Section III

IMPROVE DATA ORGANIZATION AND USE

One of the major issues in improving data collection and management is the question of how data can be more effectively stored and managed in some kind of centralized location, and then how data can be accessed from this location. Defining and evaluating options for a national data repository for earthquake data will be a major effort that will require the coordination of many different organizations as well as individual members of the research community.



III. A. Evaluate Models for a Data Repository

There are various approaches to developing a national repository that need to be evaluated carefully. The definition and evaluation of options for such a repository is a critical first step, followed by the implementation of the repository and a series of case studies or tests, encouraging users to put data in and evaluate storage and access issues.

Each of the issues identified below need to be carefully evaluated, and the costs and benefits of the various approaches need to be articulated. Clearly the repository could be established in a number of different ways, and a broad consortium of organizations and individuals, including representatives of the NEHRP agencies, need to sort through the options and evaluate the most effective approach. A national multidisciplinary, multi-agency earthquake loss working group could be established to coordinate the development of this national data repository over the next 5 years. NEES, the Network for Earthquake Engineering Simulation, is one obvious coordinator of such a data repository, by expanding their current scope of only laboratory data to include field data as well. NEES will be looked to to play a major leading role in such repository development.

Activities to identify and evaluate the options for a repository should be coordinated with existing and developing coalitions. For example, a HAZUS research coalition is looking at similar issues, including where data should be stored, and accompanying access issues. The Western Disaster Center is also exploring the possibilities of serving as an archive for data. They would collect data regionally (collecting what is readily available from governments). They would then upload and

make the data available for sharing. Efforts should be made to coordinate with these initiatives.

Any broadly based coalition or working group established to evaluate the options in creating a repository would need to resolve several basic issues, including:

▶ **III. A. a. Evaluate option for repository location**

Central to any discussion of a national data repository is the question of where such a repository should be located. Should it be a separate physical location or should it be a virtual repository, where different databases and data sets are connected via the Internet, but the data are physically stored in different libraries? Given the volume of data that could be available, both within the U.S. and internationally, multiple locations seem practical, again either virtual or a physical locations. The location issue also needs to touch on the issue of how closely a data repository should be tied to NEES, with its collaboratories and experimental data.

Three basic location models were proposed at the EERI workshop: a centralized repository, where data are brought to a central location; a virtual repository, where different databases are maintained independently but with a common architecture and are connected via the world wide web (COSMOS is the model here), and a virtual repository with a centralized back-up.

▶ **III. A. b. Evaluate options and make recommendations for types of data to be stored in repository**

A second critical issue for a data repository is the question of what types of data should be included; for example, primary data (collected from the source, such as interview data, observational data), secondary data (collected from printed reports, or other second-hand sources), data collection instruments, inventory data, and historical data. Should all data be accessible from such a repository? If not, who will decide what kinds of data are allowed; will standards for data be set up? How will the value of data be evaluated? If data are outdated, for example, should such data be included? Additionally, the working group will need to resolve if different types of data need to be separated in such a repository in terms of primary data generated by academics and professionals, and secondary source data.

Related to this is the question of who can post or upload data to a central repository. It is envisioned that there will be a wide variety of users of the repository, ranging from students to government agencies to insurers and risk modelers. Will such a wide range of users also be allowed to deposit data in the repository? Will some kind of technical review be required for posting?

▶ **III. A. c. Evaluate options and make recommendations for data standards**

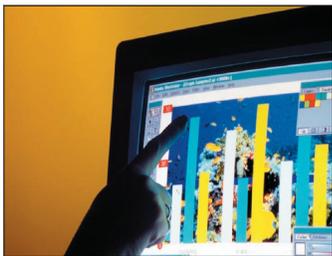
Although the issue of creating data standards needs to be addressed in the development of guidelines for data collection, including creating data dictionaries and identifying data sets that need to be collected, it is an important issue in the development of a data repository as well. The

quality and reliability of the data will be important to the sustained use and success of the repository.

Protocols should also include standards for electronic data to ensure access in future generations. Data need to be stored in a format that allows access from future systems. Some data collected after the Northridge earthquake by the State of California, for example, are no longer accessible because they are in a format that is not supported by any current technology. Data generators and researchers need to develop standards that could be widely disseminated in both communities. There might be some lessons from NASA—they have specified data formats for various levels of data they use, so that even if the technology used to generate the data does not exist in 100 years, it will still be possible to gain access to the data.

▶ **III. A. d. Evaluate options and make recommendations for creating a digital data catalog**

To insure the widespread use of the repository among researchers and practitioners in the earthquake risk reduction community, some kind of digital data catalog will need to be created and maintained. The question of linking data among various data sets will be important here. This issue is related to the creation of a data dictionary and data standards since common terms and definitions are important to the ability to retrieve data successfully.



III. B. Establish a Repository (Implementation)

Once the structure of the repository has been established, an implementation scheme for the repository needs to be developed. Implementation includes identifying those tasks that need to be completed in order to make the repository a reality, including identifying funding requirements and possible sources. The National Earthquake Hazards Reduction Program comes up for reauthorization before Congress this year, and during the reauthorization process the need for a data repository should be addressed explicitly. The reauthorization could require NEHRP agencies to compile digital databases for eventual integration into a national repository. Possible integration with FEMA's efforts in building a Multihazard Mapping Initiative (<http://www.hazardmaps.gov/>) or the Federal Geographic Data Committee (<http://www.fgdc.gov/>) should be explored.

▶ **III. B. a. Evaluate options for archiving and maintenance**

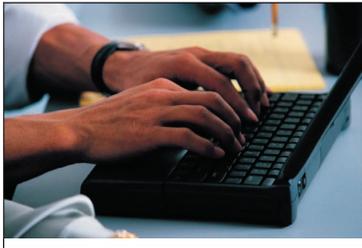
A major issue in the successful operation of a repository will be deciding what organization(s) and individuals are responsible for archiving the data, and maintaining the data. As data sets become obsolete, will the archivists delete data, update data sets, or maintain both old and new data sets? Many of the issues in archiving and maintaining will likely involve librarians as well as information technologists. These issues could also be linked to NEES, which will be addressing similar issues in its development.

▶ **III. B. b. Evaluate options for use of the data, including the development of guidelines**

Deciding who has access to the data and how the data can be used will be another important issue in the implementation of a repository. Access may in part be determined by the nature of the repository and the skill required to use it, but may also be determined by purpose of for which the data will be used. Standard guidelines that are developed by a large cross-section of the earthquake community will be key to ensuring the fair and consistent use of the repository.

▶ **III. B. c. Evaluate possible funding sources**

If the recommendation in the NEHRP post-earthquake coordination plan for funding post-earthquake investigations is not implemented, other sources of funds for what could be a very elaborate, expensive program need to be found. Workshop attendees suggested that research sponsors could be asked to pay for data maintenance. Another suggestion was that FEMA should be asked to pay for a data repository (could be used to prove the cost effectiveness of mitigation, by keeping better data from earthquake to earthquake).



III. C. Develop a Series of Case Studies to Test Models and Implementation Scheme

Once the implementation strategy has been identified, there should be a series of case studies or pilot projects created to test the functionality of the repository. Several pilot projects could build from well-organized databases from past earthquakes, while others could create data as well as explore issues in data storage and management. What are the issues in placing data in the repository? What are the issues in accessing data?



III. D. The Next Step

Defining how to organize and use data is a major undertaking that will require a significant commitment of resources, as well as the commitment of many in the broad earthquake community who will be willing to spend the time conceptualizing the structure of a data repository. Most immediately, resources need to be invested in the

basic framework for identifying and resolving the initial questions in creating a repository. Given the large number of individuals and organizations that need to be involved in identifying the structure for the repository, including questions of data standards and usage, as well as initiating the tests or case studies, significant resources for this task will be required.



CONCLUDING REMARKS

This report has identified three major tasks that will help propel the earthquake community towards an Action Plan to define the more systematic collection and management of earthquake data: Improving Data Collection, Improving Data Access, and Improving Data Organization and Use. Embedded in these three broad tasks are many complex and difficult steps that will require commitment of both individuals and financial resources over the next few years. The first step has been taken here in this document.

The steering committee suggest that the next step is to create targeted task forces that will set priorities in four important areas:

- post-earthquake damage data collection—what data need to be collected by what disciplines
- data repository(ies)—what are the critical first steps in creating such a repository? What are the development and policy issues associated with the first steps of implementing such a repository?
- secondary data collection (such as insurance data, government statistics)—what should be collected, who provides, who collects
- inventory data—how can these data be usefully incorporated into post-earthquake investigations? What are the priorities for such data?

By establishing targeted working groups, experts in each of these areas can participate in the necessary in-depth discussions leading to the setting of priorities and identification of responsible agencies and organizations and funding recommendations.

Workshop participants, the steering committee for this report, and EERI all recognize the importance of defining how to collect and manage post-earthquake data more systematically. This issue has become increasingly important as technologies are developed that allow for such systematic collection. Other organizations and programs, most importantly NEES, are also wrestling with some of the same questions. The issues identified here serve as the framework for the Action Plan that will lay out in detail how such systematic data collection and management can be handled in the next few decades.



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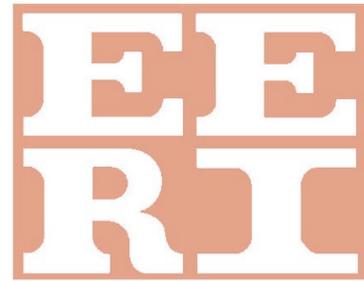
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FOOTNOTES

¹ COSMOS is the Consortium of Organizations for Strong-Motion Observation Systems. A non-profit organization, COSMOS has as its mission to expand and modernize significantly the acquisition and application of strong-motion data in order to increase public safety from earthquakes. It maintains a Virtual Data Center, a site that gives access to a relational database of strong ground motion parameters. Another of its current projects is the archiving and web dissemination of geotechnical data. Information is available from <http://www.cosmos-eq.org>.

² NEES, the Network for Earthquake Engineering Simulation, is a new major-research equipment, computation and electronic networking initiative of the National Science Foundation, whose main goal is to advance the state-of-knowledge in earthquake engineering through new methods for experimental and computational simulation. The Phase I and II deployments of NEES Equipment Sites (laboratory facilities), to be completed in 2004, include new experimental earthquake engineering equipment connected in a network for advanced experimentation using new sensing technology, high-bandwidth network communication, curated data repositories, and collaboration facilities. Formally incorporated in 2003, the NEES Consortium will be ready to operate the NEES Collaboratory (distributed resources shared by researchers and other users) for the following decade beginning in 2004. NEES will provide a unique resource for earthquake engineers to collect data, use data, and collaborate in improved simulations. The system architecture of NEES is based on grid computing which enables coordinated, flexible, secure resource sharing and problem solving among dynamic collections of individuals, institutions and resources. The current plan is for NEES to operate through at least 2014 (from EERI 2003).

³ The Federal Emergency Management Agency (FEMA), through a cooperative agreement with the National Institute of Building Sciences (NIBS) has developed a standardized, nationally applicable methodology for the estimation of losses from earthquakes, hurricanes and floods. The methodology is implemented through a PC-based Geographic Information System (GIS) software called HAZUS. The HAZUS software uses GIS technology to produce detailed maps and analytical reports that describe a community's direct physical damage (building stock, critical facilities, transportation systems, and utility systems), including induced physical damage and direct economic and social losses. (FEMA 2002). See www.hazus.org for HAZUS user group activities.

⁴ See Appendix C, "A Method for Sharing Sensitive GIS Data" by Ronald J. Langhelm, for a more detailed description of this approach at FEMA.



APPENDIX A

WORKSHOP AGENDA

AN ACTION PLAN TO DEVELOP EARTHQUAKE DAMAGE AND LOSS DATA PROTOCOLS

September 19th and 20th, 2002
Doubletree Hotel
Pasadena, California

DAY ONE: UNDERSTANDING CURRENT AND FUTURE DATA NEEDS

8 am—9 am

Registration and Continental Breakfast

9 am—9:15 am

Introduction and Welcoming Remarks

Mary Comerio, U.C. Berkeley, Organizing Committee Chair

9:15 am—9:45 am

What Exists?

Keith Porter, Caltech

Presentation summarizing findings of white paper—what currently exists in terms of data collection/
kinds of recommendations for changes that have been made

DAY ONE, CONTINUED

9:45 am—10:45 am

Panel: Visions for the Future

The NEHRP Vision: *Tom Holzer, USGS*

A Practitioner's Vision: *Charles Scawthorn, ABS Consulting*

10:45 am—11:15 am

Break

11:15—12:30 pm

Moderated Group Discussion: What is Needed?

Audience participates in a discussion on what are the problems with current data collection and management; kinds of data that are not being collected; problems with managing, access and archiving; and what is needed in the future.

Mary Comerio, Moderator

12:30 pm—2 pm

LUNCH

Presentation: How are data collected and managed elsewhere?

Agostino Goretti, Italian National Seismic Survey

2 pm—2:30 pm

Electronic Data Collection

Paul Desbler, Accela Corporation

2:30 pm—3:00 pm

Charge to the Working Groups

Identification of problems with current data collection and management/How to improve data collection/What can be recommended for the future/Action plan

Mary Comerio, Organizing Committee Chair

3:00 pm—5:00 pm

WORKING GROUP #1

How Do We Improve Data Collection? Divide by discipline. Each working group will have technical users, government representatives and commercial users.

5:30 pm

Reception for workshop participants

DAY TWO: DEVELOPING A PLAN FOR THE FUTURE

7:00 am—7:30 am

Continental Breakfast

7:30 am—9 am

WORKING GROUP #2

Divide working groups by organization type: government, academic, commercial.

Each group should address:

What the technical users want in terms of data

What the agencies want or need

What commercial users want

9—9:30 am

Break

9:30 am—11 a.m.

WORKING GROUP #3:

Divide participants to address three issues as follows:

Protocols

What kinds of protocols are necessary for collecting data?

Access

What are the current access issues?

Maintenance and Archiving

What kind of data do we want to maintain and archive, and how can this best be accomplished? Who will maintain and archive data?; Who will fund maintenance/archiving and dissemination of data?

Each working group will have technical users, government folks and commercial users. Each group will make recommendations that can become elements of the action plan.

Box lunches will be available from 11:30 am in San Gabriel Foyer. Each group takes lunch back to room. Coffee and soda also available.

11:00 am—1:00 pm

WORKING GROUP #4: How to get from here to there

(Lunch will be served during this working group)

Break into the same groups as WORKING GROUP #1. How do we get from what exists to what we'd like, based on what we've heard at this workshop?

DAY TWO, CONTINUED

1:00 pm—1:15 pm

Transition to plenary session

1:15 pm—3:00 pm

Final Plenary Session

Synthesis and Recommendations from each of the five Working Group #4

Earth sciences

Buildings

Systems/Lifelines

Modelers

Social Data

Closing Remarks: Preparing the Action Plan



APPENDIX B

LIST OF WORKSHOP PARTICIPANTS

Dan Abrams

MAE
1241 Newmark Civil Engr Laboratory
205 N Mathews Avenue, MC 250
Urbana, IL 61801-2397
Phone: 217.333.0565
Fax: 217.333.3821
Email: d-abrams@uiuc.edu

Thalia Anagnos

San Jose State University
Dept. of Civil & Environmental Engineering
San Jose, CA 95192-0083
Phone: 408.924.5190
Fax: 408.924.2444
Email: tanagnos@email.sjsu.edu

Donald Ballantyne

ABS Consulting
1411 4th Avenue Building, Suite 500
Seattle, WA 98101
Phone: 206.442.0695
Fax: 206.624.8268
Email: dballantyne@absconsulting.com

Nesrin Basoz

St Paul Fire & Marine Insurance Company
1800 Sutter Street, Suite 300
Concord, CA 94520
Phone: 925.677.7100
Fax: 925.677.7152
Email: nesrin.basoz@stpaul.com

Paolo Bazzurro

Applied Insurance Research
425 Market Street, Ste. 2200
San Francisco, CA 94105
Phone: 415.955.2662
Fax: 415.955.2664
Email: pbazzurro@air-worldwide.com

Mark Benthien

Southern California Earthquake Center
USC University Park
3651 Trousdale Parkway, Suite 169
Los Angeles, CA 90089-0742
Phone: 213.740.0323
Fax: 213.740.0011
Email: benthien@terra.usc.edu

Roger Borchardt

USGS
345 Middlefield Rd. MS 977
Menlo Park, CA 94025
Phone: 650.329.5619
Fax: 650.329.5163
Email: borchardt@usgs.gov

Ed Bortugno

Governor's Office of Emergency Services
P.O. Box 419023
Rancho Cordova, CA 95741-9023
Phone:
Email: edward_bortugno@oes.ca.gov

Linda Bourque

University of California Los Angeles
School of Public Health
Box 951772
Los Angeles, CA 90095-1772
Phone: 310.825.4053
Fax: 310.825.8440
Email: lbourque@ucla.edu

Jonathan Bray

UC Berkeley
Dept. of Civil & Environmental Engineering
440 Davis Hall MC 1710
Berkeley, CA 94720-1710
Phone: 510.642.9843
Fax: 510.642.7476
Email: bray@ce.berkeley.edu

Ian Buckle

University of Nevada Reno
Dept. of Civil Engineering
Mail Stop 258
Reno, NV 89557
Phone: 775.784.1519
Fax: 775.784.4213
Email: igbuckle@unr.edu

Mary Comerio

UC Berkeley
Architecture Dept.
232 Wurster Hall
Berkeley, CA 94720-1800
Phone: 510.642.2406
Fax: 510.643.5607
Email: mcomerio@uclink.berkeley.edu

Scott Deaton

Data Forensics
576 Maribee Drive
Tucker, GA 30084
Phone: 404.435.6626
Email: sdeaton@dataforensics.net

Paul Deshler

Accela, Inc.
5 Twins Arrows
Flagstaff, AZ 86004
Phone: 801.403.3544
Fax: 801.821.2081 (pause) 1020 (810?)
Email: pdeshler@accela.com

Weimin Dong

RMS, Inc.
7015 Gateway Blvd.
Newark, CA 94560-1011
Phone: 510.608.3356
Fax: 510.505.2501
Email: weimind@rms.com

Dan Dyce

California Earthquake Authority
3033 Gold Canal Road
Rancho Cordova, CA 94571
Phone: 916.853.4400
Fax: 916.464.1190
Email: dyced@calquake.com

Ronald Eguchi

ImageCat Inc.
Union Bank of California Building
400 Oceangate, Suite 1050
Long Beach, CA 90802
Phone: 562.628.1675
Fax: 562.628.1676
Email: rte@imagecatinc.com

John Eidinger

G & E Engineering Systems, Inc.
6315 Swainland Rd.
Oakland, CA 94611-1843
Phone: 510.595.9453
Fax: 510.595.9454
Email: eidinger@earthlink.net

Steven French

MAE/Georgia Institute of Technology
Center for Geographic Information Systems
790 Atlantic Drive
Atlanta, GA 30332-0695
Phone: 404.385.0900
Fax: 404.385.0450
Email: steve.french@arch.gatech.edu

Joe Futrelle

152 Computer Applications Building
605 E. Springfield Avenue
Champaign, IL 61820
Phone: 217.265.0296
Fax: 217.244.1987
Email: futrelle@ncsa.uiuc.edu

Lind Gee

University of California Berkeley
Seismological Laboratory
215 McCone Hall
Berkeley, CA 94720-4760
Phone: 510.643.9449
Fax: 510.643.5811
Email: lind@seismo.berkeley.edu

Agostino Goretti

Servizio Sismico Nazionale
Via Curtatone, 3
Roma, ITALY 00185
Phone: 011.39.335.5391531
Email: agostino.goretti@serviziosismico.it

Vladimir Graizer

California Geological Survey
Strong Motion Instrumentation Program
801 K Street, MS 13-35
Sacramento, CA 95814-3531
Phone: 916.322.7481
Fax: 916.323.7778

Marjorie Greene

Earthquake Engineering Research Institute
499 14th Street, Suite 320
Oakland, CA 94612
Phone: 510.451.0905
Fax: 510.451.5411
Email: mgreene@eeri.org

Patricia Grossi

Southern Methodist University
Cox School of Business ITOM Dept
P.O. Box 750333
6212 Bishop Blvd.
Dallas, TX 75275
Phone: 214.768.4170
Fax: 214.768.4099
Email: pgrossi@mail.cox.smu.edu

Robert Hanson

University of Michigan, Emeritus
2926 Saklan Indian Drive
Walnut Creek, CA 94595
Phone: 925.946.9463
Fax: 925.256.4693
Email: robert.hanson@fema.gov

John Hayes

Construction Engineering Research Laboratory
U.S. Army Engineer Research/Dvlpmnt Center
Attn: CEERD-CF-M
2902 Newmark Drive
Champaign, IL 61822-1076
Phone: 217.373.7248
Fax: 217.373.6734
Email: j-hayes@cecer.army.mil

William Holmes

Rutherford & Chekene
427 Thirteenth Street
Oakland, CA 94612
Phone: 510.740.3200
Fax: 510.740.3340
Email: wholmes@ruthchek.com

Tom Holzer

USGS
345 Middlefield Road
Menlo Park, CA 94025-3591
Phone: 650.329.5637
Email: tholzer@usgs.gov

Wilfred Iwan

California Institute of Technology
Earthquake Engr Research Lab
MC 104-44
Pasadena, CA 91125
Phone: 626.395.4144
Fax: 626 568.2719
Email: wdiwan@caltech.edu

Anke Kamrath

University of California, San Diego
San Diego Supercomputer Center
9500 Gilman Drive, MC 0505
San Diego, CA 92093-0505
Phone: 858.534.5140
Email: kamratha@sdsc.edu

David Kehrlein

OES Team IT
Governor's Office of Emergency Services
P.O. Box 419047
Rancho Cordova, CA 95741-9047
Phone: 916.845.8541
Email: David_Kehrlein@oes.ca.gov

Charles Kircher

Kircher & Associates
1121 San Antonio Road, Ste D-202
Palo Alto, CA 94303-4311
Phone: 650.968.3939
Fax: 650.968.0960
Email: cakircher@aol.com

Ron Langhelm

FEMA Region X
130 228th Street SW
Bothell, WA 98021
Phone: 425.487.4642
Email: ron.langhelm@fema.gov

Bill Lettis

William Lettis & Associates
1777 Botelho Drive, Suite 262
Walnut Creek, CA 94596
Phone: 925.256.6070
Fax: 925.256.6076
Email: lettis@lettis.com

Jay Love

Degenkolb Engineers
300 Frank H Ogawa Plaza, Suite 450
Oakland, CA 94612
Phone: 510.272.9040
Fax: 510.272.9526
Email: rjlove@degenkolb.com

Michael Mahoney

FEMA
Natl EQ Program Office
500 C Street SW, Room 416
Washington, DC 20472
Phone: 202.646.2794
Email: mike.mahoney@fema.gov

Joshua Marrow

Simpson Gumpertz & Heger Inc
222 Sutter Street, Suite 300
San Francisco, CA 94108
Phone: 415.495.3700
Fax: 415.495.3550
Email: jmmarrow@sgh.com

Kurt McMullin

San Jose State University
Dept. of Civil Engineering
One Washington Square
San Jose, CA 95192-0083
Phone: 408.924.3855
Fax: 408.924.4004
Email: mcmullin@email.sjsu.edu

Jacqueline Meszaros

University of Washington
18115 Campus Way NE, UW-2, Room 337
Bothell, WA 98011-8246
Phone: 425.352.5282
Email: meszaros@u.washington.edu

Dennis Mileti

University of Colorado
Natural Hazards Center
482 UCB
Boulder, CO 80309-0482
Phone: 303.492.6818
Fax: 303.492.2151
Email: dennis.mileti@colorado.edu

Farzad Naeim

John A Martin & Associates Inc
1212 S Flower Street, 4th Floor
Los Angeles, CA 90015
Phone: 213.483.6490
Fax: 213.483.3084
Email: farzad@johnmartin.com

Stuart Nishenko

Pacific Gas & Electric
Geosciences Dept.
MC NAC, P.O. Box 770000
San Francisco, CA 94177
Phone: 415.973.1213
Fax: 415.973.5778
Email: spn3@pge.com

Rob Olshansky

University of Illinois at Urbana-Champaign
Urban & Regional Planning
111 Temple Hoyne Buell Hall
611 Taft Drive
Champaign, IL 61820
Phone: 217.333.8703
Fax: 217.244.1717
Email: robo@uiuc.edu

John O'Sullivan

Caltrans
Office of EQ Engineering, MS9
1801 30th Street, PO Box 168041
Sacramento, CA 95816-8041
Phone: 916.227.5206
Email: john_o'sullivan@dot.ca.gov

Jeanne Perkins

Association of Bay Area Governments
101 Eighth Street
P.O. Box 2050
Oakland, CA 94607
Phone: 510.464.7934
Fax: 510.464.7970
Email: jeannep@abag.ca.gov

Keith Porter

California Institute of Technology
1200 E California Blvd., MC104-44
Pasadena, CA 91125
Phone: 626.395.4141
Fax: 626.568.2719
Email: keithp@caltech.edu

Charles Real

California Geological Survey
801 K Street, MS 12-31
Sacramento, CA 95814-3531
Phone: 916.323.8550
Fax: 916.445.3531
Email: creal@consvr.ca.gov

Robert Reitherman

CUREE
1301 S. 46th Street
Richmond, CA 94804-4698
Phone: 510.231.9557
Fax: 510.231.5664
Email: reitherman@curee.org

Christopher Rojahn

ATC
555 Twin Dolphin Dr. Suite 550
Redwood City, CA 94065-2137
Phone: 650.595.1542
Fax: 650.593.2320
Email: crojahn@atcouncil.org

Richard Roth, Jr.

California Insurance Actuaries
8821 Baywood Drive
Huntington Beach, CA 92646
Phone: 714.964.7814
Fax: 714.964.2896
Email: rothjr@ix.netcom.com

Badie Rowshandel

California Geological Survey
801 K Street, MS 12-32
Sacramento, CA 95814
Phone: 916.322.9312
Fax: 916.322.4765
Email: browshan@constrv.ca.gov

James Russell

Building Codes Consultant
3654 Sun View Way
Concord, CA 94520
Phone: 925.687.1974
Fax: 925.827.1314
Email: jerussell.luddite@worldnet.att.net

Michael Sabbaghian

Office of Emergency Services
Technical Assistance Programs
P.O. Box 419047
Rancho Cordova, CA 95741-9047
Phone: 916.845.8266
Fax: 916.845.8474
Email: Michael_Sabbaghian@oes.ca.gov

Stephen Sahs

Caltrans
Office of EQ Engineering MS9
1801 30th Street, PO Box 168041
Sacramento, CA 95816-8041
Phone: 916.227.7928
Email: steve_sahs@dot.ca.gov

Charles Scawthorn

ABS Consulting
1111 Broadway, 10th Floor
Oakland, CA 94607-5500
Phone: 510.817.3153
Fax: 510.663.1046
Email: cscawthorn@absconsulting.com

Hope Seligson

ABS Consulting
300 Commerce Drive, Ste. 200
Irvine, CA 92602
Phone: 714.734.4242
Fax: 714.734.4262
Email: hseligson@absconsulting.com

Kimberley Shoaf

UCLA, School of Public Health
10911 Weyburn Ave. Suite 208
Box 951772
Los Angeles, CA 90095-1772
Phone: 310.794.0840
Fax: 310.794.0889
Email: kshoaf@ucla.edu

Kathleen Tierney

University of Delaware
Disaster Research Center
77 East Main Street, Room 106
Newark, DE 19716
Phone: 302.831.6618
Fax: 302.831.2091
Email: tierney@udel.edu

Susan Tubbesing

Earthquake Engineering Research Institute
499 14th Street, Suite 320
Oakland, CA 94612
Phone: 510.451.0905
Fax: 510.451.5411
Email: skt@eeri.org

Fred Turner

California Seismic Safety Commission
1755 Creekside Oaks Drive, Ste. 100
Sacramento, CA 95833
Phone: 916.263.0582
Fax: 916.263.0594
Email: fturner@quiknet.com

Xena van de Walle

Earthquake Engineering Research Institute
499 14th Street, Suite 320
Oakland, CA 94612
Phone: 510.451.0905
Fax: 510.451.5411
Email: xena@eeri.org

David Wald

USGS
525 S. Wilson Avenue
Pasadena, CA 91106
Phone: 626.583.7238
Fax: 626.583.7827
Email: wald@usgs.gov

Dennis Wenger

NSF
Division of Civil & Mechanical Systems
4201 Wilson Blvd
Arlington, VA 22230
Phone: 703.292.7014
Fax: 703.292.9053
Email: dwenger@nsf.gov

Chris Wills

California Geological Survey
185 Berry Street, Suite 210
San Francisco, CA 94107-1729
Phone: 415.904.7729
Fax: 415.904.7715
Email: cwills@constrv.ca.gov

Mark Yashinsky

Caltrans
Office of EQ Engineering MS9
1801 30th Street, PO Box 168041
Sacramento, CA 95816-8041
Phone: 916.227.8719
Fax: 916.227.8898
Email: mark_yashinsky@dot.ca.gov

Philip Yen

Federal Highway Administration
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101
Phone: 703.493.3056
Email: wen-huei.yen@fhwa.dot.gov



APPENDIX C

A METHOD FOR SHARING SENSITIVE GIS DATA

BY RONALD LANGHELM, FEMA REGION X

A METHOD FOR SHARING SENSITIVE GIS DATA

Ronald J. Langhelm

Technical Services Branch Chief, FEMA ERT-N Red Team
GIS Coordinator, FEMA Region X
130 228th ST SW
Bothell, WA 98021
Ron.Langhelm@fema.gov

Geographic Information Staff (GIS) often encounter roadblocks acquiring various types of sensitive data. During the recovery efforts under FEMA-1361-DR-WA resulting from the Nisqually Earthquake (February 28, 2001), the FEMA GIS team once found itself on the side of “information holder” instead of “information seeker”. Due to the requirement that FEMA uphold the protections afforded to disaster applicants in the Privacy act, it was difficult to share FEMA data with the public.

One of FEMA’s most valuable sources of data is the Human Services module in the National Emergency Management Information System (NEMIS), which stores all information regarding disaster assistance applicants’ damage information, including damage location, contact information, income information, and specific damages to the homes and/or properties. All of the information included in NEMIS is protected by the Privacy Act and as such, can only be shared in very non-descript formats so as not to violate the Privacy Act information sharing restrictions. Immediately following the earthquake, FEMA GIS staff began aggregating agency data to zip code and census geographies to facilitate data sharing. We continued to receive requests for more detailed data, as the large-scale geographies were not useful in areas where the population was less dense.

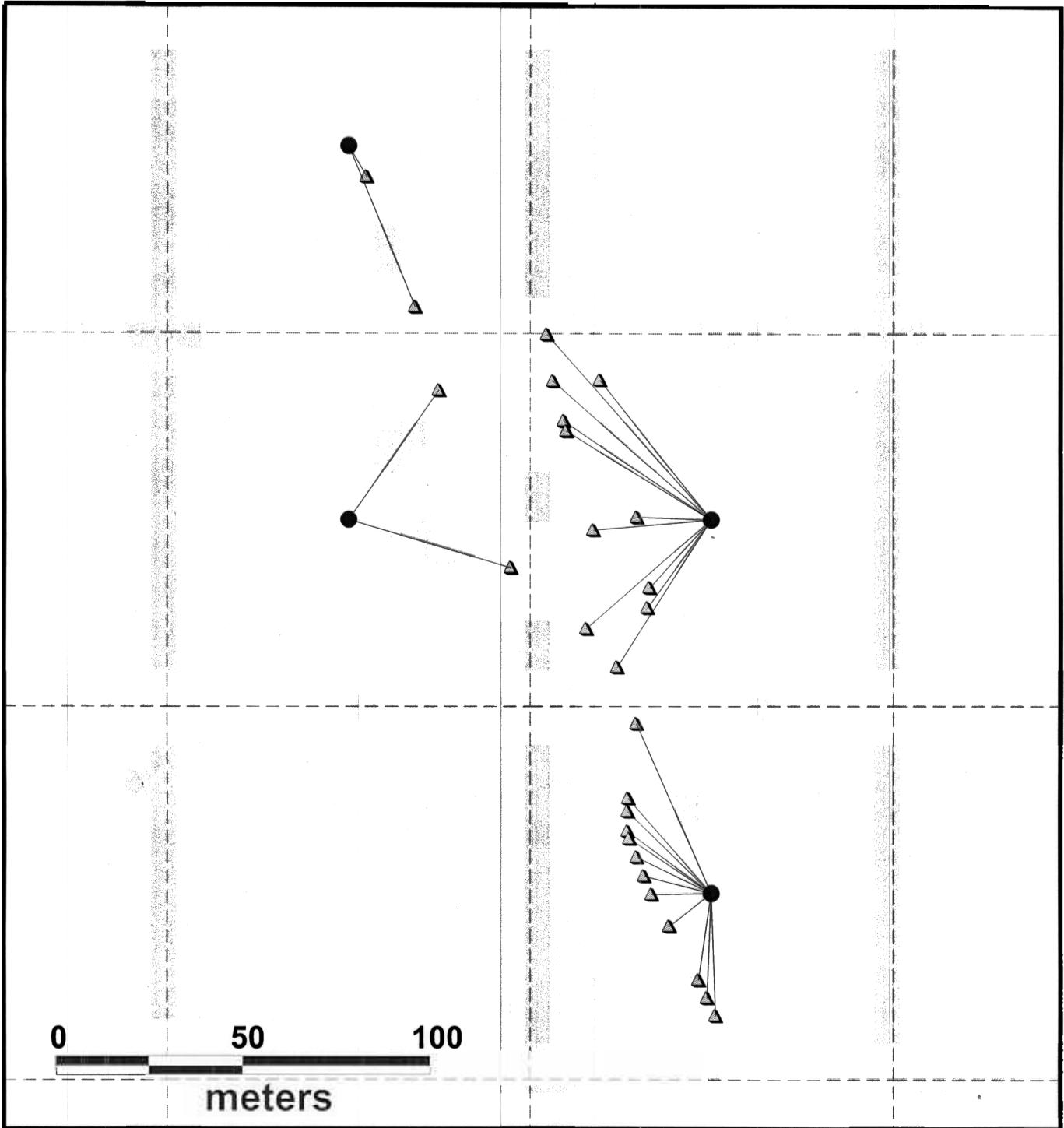
In an effort to find middle-ground between Privacy Act limitations and repeated requests for earthquake damage data from public entities, we began to use a 100-meter grid for data aggregation. Two to three months into the disaster, the grid was developed and GIS staff began to work on the application that would create the final data. The system is designed to aggregate any dataset to the designated 100m grid and assign a second set of coordinates from the centroid of the grid cell within which the sensitive data falls. Using the new coordinates and the non-sensitive attribute information, a new point coverage is created that provides more useful information to the data user and protects the privacy of the applicants.

FEMA’s Office of General Council has approved the release of sensitive data aggregated to a 100m grid where there are greater than 5 occurrences in the grid cell. Attached is a sample map displaying the data.



REGION X

Sensitive Data Points Generalized to 100m Grid Centroid



Explanation:

Red circles represent new locations for sensitive data.
The original locations are displayed as green triangles
with lines to their generalized location.



APPENDIX D

LEARNING FROM EARTHQUAKES: A SURVEY OF SURVEYS

By Keith Porter, M. EERI

This paper presents a literature review of efforts to learn from earthquakes: collecting, archiving, and disseminating information. The emphasis is on primary sources, i.e., data-gathering instruments or investigations that include direct observation of earthquake effects. The study addresses seismology and geotechnical engineering; safety and damage to individual buildings; performance of large numbers of buildings and of particular structure types; damage to nonstructural components, lifelines, and industrial equipment; socioeconomic impacts including casualties and business interruption; insurance loss data; and methods and databases that characterize existing facilities. The present paper also examines a few efforts to aggregate data across studies, to incorporate data into predictive models, or to disseminate information for use by others, with attention to how well primary sources meet these needs. A number of common themes appear in the publications examined here. These include the need to document for both data-gatherers and readers clear procedures and definitions; the value of publishing raw data and data-gathering instruments to support conclusions and to allow for aggregating data with efforts by others; the value of standard facility-description and damage categorization systems; avoidance of data loss by publishing in multiple formats and media; the value of coordinating data-gathering efforts and disseminating common tools and databases; the need to provide for statistical analysis; the danger of over-aggregation; the value of providing incentives to survey respondents; the importance of dense instrumentation; the use of predictive tools for data-gathering; and the need for a permanent, curated earthquake experience data archive.

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INTRODUCTION

OBJECTIVES

The scientific aspects of earthquake engineering follow the pattern of all science: observation, hypothesis, prediction of the consequences of that hypothesis, and observations to test those predictions. In the case of earthquake engineering, laboratory experimentation can be used to test many hypotheses, and much valuable science can be developed using reaction walls, shake tables, centrifuges, and computer simulations. Nonetheless, many systems are too large and costly to test in the lab, so we turn to the real-world laboratory of earthquake experience.

The problems with the real-world laboratory are that earthquakes occur infrequently, much of the damage and loss data are highly perishable, and the data can be expensive to gather. Earthquake engineers must therefore be prepared before the earthquake to gather the *right* data—data needed to improve foreseeable preparedness, response and recovery decisions, and data needed to test scientific hypotheses—and to make these data available to the professional and research community. The questions addressed by this paper are:

- What are the right data, and how should they be gathered and disseminated?
- What resources currently exist to aid in learning from earthquakes?

To answer these questions, this paper reviews past efforts to learn from earthquakes. It surveys historic data-collection protocols and dissemination efforts, and presents lessons learned from these efforts. The range of topics on which earthquake data are gathered is quite diverse, making an exhaustive survey impractical. Only a limited sample of references on each topic is examined here. For each reference, the authors' objectives are briefly summarized, along with their approach, the lessons they draw from their efforts, and in some cases, additional lessons that can be extracted for present purposes.

Topics addressed here include issues of seismology, geotechnical engineering, structural engineering, casualties, and business impacts. In addition to post-earthquake data gathering, some attention is paid to recent studies that use historic data gathered by others, and the conclusions these authors draw about data-collection needs. Some important topics are ignored, such as ground failure, tsunami, fire following earthquake, emergency services, and indirect economic losses.

This paper is accompanied by an electronic appendix that contains copies of various data-collection forms, data categorization systems, and other reference material. These materials would be too voluminous to include in the main body of the report, but should nonetheless be available for reference. The electronic appendix is also offered as an example of how raw data and data-collection instruments can be thoroughly documented without sacrificing brevity in a summary article.

PREVIOUS LITERATURE REVIEW

Past studies have examined the question of how best to gather post-earthquake data. As part of the **NEHRP Conference and Workshop on Research on the Northridge, California Earthquake of January 17, 1994 (CUREE 1997)**, 18 experts in 11 sub-disciplines offer a series of one- to two-page overview statements, addressing among other questions, how future post-earthquake research should be conducted compared with the general pattern of the Northridge Earthquake. Although the most common answer was “with more money” (five of 18 mentioned funding), four of the experts urged advanced planning for multiple PIs to gather specific, fragile, or statistical data using a common, standard

methodology. Other common specific answers were coordination conferences, better coordination with transportation agencies, and more attention to multiple-year research.

GENERAL RECONNAISSANCE

EERI FIELD INVESTIGATION PROCEDURES

Before examining specialized earthquake loss-data collection efforts, consider the general effort undertaken by the Earthquake Engineering Research Institute (EERI) to collect earthquake experience information. The **Earthquake Engineering Research Institute's (2000) Post-Earthquake Investigation Field Guide** specifies procedures for rapid earthquake reconnaissance of a nearly exhaustive set of earthquake phenomena: geoscience and geotechnical engineering; tsunamis; nature of and damage to engineered buildings and industrial facilities; lifelines and transportation structures; architectural and nonstructural elements; emergency management and response; societal impacts; and urban planning and public policy.

These two-page forms query the surveyor for summary information about the facility that is subject to loss, along with mostly expository descriptions of the performance of the feature in question, as opposed to selection from predefined lists or recording of well-defined numerical performance metrics. The forms are distributed in paper and electronic format. (Copies are included in the electronic appendix of this paper.) Currently, they are filled out on paper, although EERI is exploring implementing these forms on palmtop computers, wireless communication, and a centralized database.

The EERI forms are useful for providing information about the nature of geotechnical and engineering failure and consequent losses. The surveyor can use the forms to document failure modes, factors that may have contributed to failure, and secondary impacts. They primarily serve to focus attention on novel phenomena and to answer the question of whether anything unusual or unexpected happened. They do not provide statistical information, and cannot be used to inform damage or loss models for purposes of quantifying performance or estimating the benefits of mitigation. Data analysis is left to the reconnaissance team. No procedures are specified for publishing the raw data forms.

GENERAL PROGRAMS FOR DATA COLLECTION

The National Earthquake Hazards Reduction Program (NEHRP) has recently drafted a **Plan to Coordinate NEHRP Post-Earthquake Investigations (Holzer et al. 2002)**. The draft plan specifies “a framework for both coordinating what is going to be done and identifying responsibilities for post-earthquake investigations.” While the plan does not specify particular data-gathering efforts that should be performed, it proposes nine scheduled tasks to facilitate these efforts, and assigns them to various NEHRP agencies and other entities: (1) implement the plan for potentially damaging earthquakes; (2) establish an incident website; (3) establish a field coordination clearinghouse; (4) select an individual to coordinate NEHRP investigations; (5) meet to summarize initial reconnaissance results and to recommend further data-gathering efforts; (6) meet to discuss supplemental funding (this task is not yet definite); (7) convene a workshop to prioritize investigations; (8) solicit investigation proposals; and (9) disseminate results. It offers four recommendations to improve the comprehensiveness

and efficiency of earthquake investigations and data archiving. These are: improve documentation of performance data; increase the use of information technology; formalize data management and archiving; and establish appropriate funding for post-earthquake investigations.

Reitherman (1998) proposes the development of a program of study for collecting nonstructural-component performance data. He offers general recommendations for such a program, rather than discussing particular data-collection protocols or categories of nonstructural components to be studied. He urges that, whatever survey instruments are used, they should be used to gather statistical data from large numbers of facilities, with subsequent study in greater depth on a smaller sample of facilities. The data to be gathered should indicate the fraction of nonstructural components of various categories in various performance levels, when subjected to various levels of seismic excitation. The author estimates that the cost to perform such studies at \$750,000 for an event similar to the 1994 Northridge Earthquake, increasing by a factor of 1.5 for every doubling of the size of the event, measured in terms of direct property loss.

SEISMOLOGY AND GEOTECHNICAL ENGINEERING

SEISMIC SOURCES AND GROUND-MOTION TIME HISTORIES

Consider now efforts to gather, analyze, and disseminate particular earthquake data. **TriNet (2002)** is a collaborative project to determine seismic sources and collect seismograms and accelerograms for Southern California. It uses a network of 600 stations distributed throughout Southern California, of which approximately 450 have strong-motion instruments, and 150 that have both broadband seismometers and strong-motion accelerometers. The latter set provides continuous digital telemetry via TCP/IP to a central computing facility and to a redundant, active standby facility. The former send their recordings when triggered.

When the instruments indicate that an earthquake has occurred, the central computing facility automatically determines the earthquake origin time, magnitude, location, and source information in near-real-time. Staff seismologists review computed earthquake information, and web servers display the information via a website. This infrastructure collects and archives the continuous telemetry at 20 samples per second. This means that anyone can recall a record from any of these 150 TriNet sites from any point in time since the instrument was installed, for any duration of interest. Furthermore, higher-sampling-rate records (up to 100 samples per second) are archived and available for any instrument in a region near an earthquake of magnitude $M \geq 1.8$, and from the entire network for events of magnitude $M \geq 4$. TriNet is thorough.

TriNet began in 1997, a successor to earlier programs such as the 1990 Caltech US Geological Survey Broadcast of Earthquakes (CUBE) project to provide real-time earthquake information. The system is a collaborative effort of the California Institute of Technology, the U.S. Geological Survey, and the California Geological Survey (formerly the California Division of Mines and Geology). In 2002, TriNet finished, and merged with a similar, Northern-California effort to become the **California Integrated Seismic Network (CISN 2001)**. CISN in turn will represent the California region of the currently-developing **Advanced National Seismic System (ANSS, U.S. Geological Survey 2000a)**, which if fully funded will be similar to TriNet and CISN, but with a national scope, a more extensive seismic network, and with the addition of instruments in buildings.

The methodologies for determining source information are fairly mature. TriNet, CISN, and

eventually ANSS, represent examples of how these methodologies are implemented with sensors, communication, and computer facilities to provide publicly available, rapid, reliable estimates of source mechanism, origin time, location, and magnitude. The archive makes it easy to retrieve these earthquake data at a later time.

Note that the sensors in TriNet and CISN are primarily free-field instruments, important for determining source information, but of limited value for structural engineering purposes, at least compared with instruments in important facilities. There is however no fundamental difference between free-field strong-motion accelerometers and accelerometers in buildings. Consequently, there is no reason why these networks could not be used as resources for collecting and disseminating building-motion data, other than institutional barriers and priority differences between seismologists and structural engineers.

The California Strong-Motion Instrumentation Program (CSMIP, California Geological Survey 2002a) since 1972 has maintained a network of accelerographs to measure strong shaking. In 2002, the network includes more than 900 stations: 650 record ground motion, 170 stations are located in buildings, 20 are on dams and 60 on bridges. The more modern of these instruments sends its telemetry automatically to CSMIP headquarters when it experiences strong motion. The strong-motion data are available for download from the California Geological Survey's Strong Motion Data Center (California Geological Survey 1999).

The Consortium of Organizations for Strong-Motion Observation Systems (COSMOS 2002a) offers an alternative to the TriNet-CISN paradigm for disseminating waveform data. COSMOS provides a database of strong-motion recordings of earthquakes in the United States, Canada, Mexico, Central America, South America, Japan, Taiwan, New Zealand, Armenia, Turkey, and elsewhere. The novelty of this database is that the recordings are collected and maintained by the member institutions such as CSMIP, not by COSMOS itself. COSMOS instead offers a virtual datacenter, virtual in that it provides pointers to the data that the member networks actually maintain. The distinction is immaterial to the user, who sees a nearly seamless dataset of worldwide recordings. Because of the variety of data sources, the strong-motion recordings vary in formats, but these formats are fully defined at the COSMOS site.

SHAKING SEVERITY

Byerly and Dyk (1936) offer an early methodology used to gather data for regional intensity maps. The authors describe a method to ascertain subjective ground-motion intensity measures using postcard questionnaires. The authors find that, when such questionnaires are sent after an earthquake has occurred, the reply rate is low. They improved upon this system by ensuring that postcards are kept on hand by preestablished correspondents. Postmasters, field engineers of an oil company, and employees of large public-service corporations were secured as regular reporters. The questions asked on the questionnaire can be used to determine intensity according to the Modified Mercalli Intensity (MMI) scale. The new system generated large numbers of replies—thousands per year between 1930 and 1936. The authors also address dissemination of results. Duplicate indexed archives were maintained in Pasadena, the University of California at Berkeley, and Washington, D.C. Archives were publicly available. A sample questionnaire is provided in the electronic appendix to the present report.

While instrumental measures of ground motion have largely eclipsed subjective measures (with the notable exception of “Did you feel it?” as described below), one can draw several conclusions and

recommendations that are relevant today:

1. *Manage reporting in advance.* Reporting material should be in the hands of skilled and impartial correspondents before the earthquake occurs.
2. *Refresh the reporting process regularly.* The authors recommend reminding correspondents that ongoing data-collection programs are still active and expressing appreciation for their reports.
3. *Human reactions matter.* The authors find that questionnaires are useful checks or supplements to instrumental measures.
4. *Partiality matters.* The authors argue that volunteers who come forward and show interest in the subject are “not the best observers, since they are concerned with some particular theory ... rather than [reporting] the phenomena exhibited by the shock.”
5. *Data should be publicly available.* The general availability of publicly collected data is not a given. The authors went to special effort to ensure their availability.

“Did you feel it?” (U.S. Geological Survey 2001) is a 21st-Century approach to creating regional subjective intensity maps, called Community Internet Intensity Maps (CIIM). It uses an Internet-based system that provides, collects, and analyzes questionnaires from the public. The questionnaire allows people who actually experienced an earthquake to describe their experience, the effects of the earthquake, and the extent of damage. It uses an algorithm developed by Dengler and Dewey (1998) for determining community decimal intensity. (Community decimal intensity is similar to MMI but with intensity measured in decimal terms.) Wald et al. (1999) have adapted Dengler and Dewey’s (1998) phone-survey approach for this Internet application. The resulting questionnaire, a sample of which is provided in the electronic appendix of this report, includes questions on the correspondent’s identify, location, situation during the earthquake (i.e., indoors, outdoors, etc.), qualitative description of the shaking (weak, mild ... violent), duration of motion, personal reaction, and visible effect of the earthquake on structures and objects.

There are interesting similarities and contrasts between the CIIM system and that described by Byerly and Dyk (1936). Both cases use a standard questionnaire that relates directly to the MMI scale. Both manage the reporting in advance. Both allow for direct comparison between subjective and instrumental intensity measurements. Byerly and Dyk (1936) rely on preestablished, disinterested correspondents, whereas the CIIM process relies on volunteers who come forward and show interest in the subject, although CIIM accounts for the resulting bias. Both provide detailed data for public use in archival locations, although “Did you feel it?” provides raw data only after they are stripped of personal information, by request from the U.S. Geological Survey, Pasadena office (Wald, 2002).

ShakeMap (TriNet 2001) is a product of TriNet and CISN that uses the strong-motion network to create maps of shaking severity. These images, called ShakeMaps, display shaking severity for individual events in units of peak horizontal ground acceleration, peak ground velocity, and instrumental intensity (an estimate of MMI based on instrumental measurements). ShakeMaps are available in a format that can be input to the HAZUS software (Federal Emergency Management Agency 1999) for use in loss estimation. The ShakeMap working group notes that, with the current station distribution, data gaps are common, particularly for smaller events and earthquakes near or outside the edge of the network. They also note that, “Since ground motions and intensities typically can vary significantly over small distances, these maps are only approximate. At small scales, they should be considered unreliable.” Conclusions:

1. *ShakeMaps are valuable at the macros scale.* They provide a rapid, readily comprehensible, and reasonably accurate macro-level shaking severity within minutes of the occurrence of strong shaking. These

maps are well archived, easily retrievable, and consciously integrated with public loss-estimation software.

2. *ShakeMaps are limited by the density of stations available.* To employ ShakeMaps for ground-shaking assessment at the building-specific level will require a much greater density of instruments.
3. *ShakeMaps do not depict ground failure.* Perhaps 5-10% of earthquake damage is attributable to landslide, liquefaction, lateral spreading, and faulting. This peril is not depicted by ShakeMap, although research efforts to do so are underway (Wald, 2002).

SITE CONDITIONS

One can divide site data into two categories: (1) regional maps showing engineering geology, faulting, liquefaction, and landslide, and (2) site soil boring logs that show a profile of soil material, water content, and density. There exists in the United State no centralized entity like COSMOS or CISN to compile and disseminate this category of earthquake information. Various government and private entities collect, maintain, and disseminate maps of active fault traces, landslide and liquefaction hazard, regional and local engineering geology, and soil borings.

Regional Maps

The U.S Geological Survey's **National Geologic Map Database Project (U.S. Geological Survey 2000b)** provides a GIS-enabled searchable bibliography of paper maps and sources for obtaining them. Some text publications are available online; maps are typically available only in paper format. Some states publish additional information. A notable example is the **California Geological Survey (2002b, c, d)**, which distributes paper and downloadable electronic maps of fault-rupture zones, the state geologic map at various scales, and maps showing liquefaction and landslide potential. The maps can be informative of general site conditions for a building, such as approximate wave velocity, proximity of fault traces, and gross liquefaction and landslide potential.

Soil Borings

Soil-boring logs are more valuable than regional maps for discerning site characteristics. They are typically created for large structures as part of geotechnical studies for foundation design, and provide crucial information for characterizing and understanding site amplification and ground-failure potential. The geologic studies are available for a limited number of sites from city building departments. In addition, utilities and transportation departments can maintain large collections of soil-boring logs for their facilities.

At present there is no general index of locations where such borings are available, but one appears to be developing. A collaborative effort called **ROSRINE (Resolution of Site Response Issues from the Northridge Earthquake 2000)** has collected and disseminates via a web page soil-boring logs for (currently) 45 strong-motion sites, for purposes of understanding the response of these instruments in the Northridge Earthquake. The ROSRINE project has served as impetus to a multi-agency project called the **Virtual Geotechnical Database (COSMOS 2002b)**. The short-term goal of this entity is to develop a pilot web-based system to link and disseminate geotechnical data possessed by Caltrans, Pacific Gas and Electric (PG&E), the California Geological Survey, and the U.S. Geological Survey. Its long-term goal, not yet funded as of this writing, is "to extend the pilot system and develop a web-based system linking multiple data sets, capable of serving the broad needs

of practicing geotechnical and earthquake hazards professionals for efficient access to geotechnical data.” COSMOS and the Lifelines Project of the Pacific Earthquake Engineering Research (PEER) Center are currently developing the pilot system, and have not yet determined the standards, technologies, data types and formats, access method, and interface of this virtual database.

BUILDINGS

BUILDING AND OCCUPANCY CATEGORIES

The **HAZUS Technical Manual (NIBS and FEMA 1999)** describes technical details underlying the HAZUS loss-estimation software. The manual does not address post-earthquake data gathering, and FEMA publishes no tool specifically designed to gather HAZUS-relevant earthquake experience. Nonetheless, HAZUS is widely used and represents a national standard, so it would be valuable for validating and improving the software if model building type, occupancy class, and damage and loss data were gathered according to HAZUS terminology. (HAZUS models a variety of facility types and perils; only buildings and earthquakes are discussed here.)

HAZUS characterizes occupancies in 28 classes, and buildings in 36 model building types. The model building types are defined using 16 structural systems and up to three height ranges. In addition, buildings are associated with one of four seismic design levels that reflect regional hazard level and era of construction. Nonstructural components are categorized by 17 types of architectural, mechanical, electrical, and plumbing components, and six types of contents. Building locations are characterized either by latitude and longitude or census tract. The electronic appendix of the present paper contains a listing of these occupancy classes, building types, design levels, and nonstructural-component categories.

HAZUS estimates building damage states for each of three features: structural components, nonstructural drift-sensitive components, and nonstructural acceleration-sensitive components. There are five possible damage states, from “none” to “complete,” each provided with qualitative descriptions of the damage for each model building type and a point repair cost per square foot of building area by model building type and occupancy class. The manual provides only discrete values of repair costs are provided for each damage state, rather than ranges. However, one can equate the damage states with the following ranges of damage factor, according to the developer (Bouabid, 2003). (Damage factor is defined here as repair cost as a fraction of replacement cost, new). Slight damage corresponds to damage factors of 0-5%; moderate corresponds to 5-20%; extensive corresponds to 20-50%, and complete corresponds to 50-100%. These ranges are not formalized or definite, however, and Bouabid indicates that ranges of 0-2%, 2-15%, 15-40%, and 40-100% for slight, moderate, extensive, and complete, respectively, are also valid.

SEISMIC ATTRIBUTES OF EXISTING BUILDINGS

ATC-50 (Applied Technology Council, 2001 draft) is not a post-earthquake data-gathering tool, but it is interesting for the present study because of its five-page assessment form. A structural engineer can use this form to characterize 37 attributes of woodframe dwellings that are believed to relate to the building’s seismic vulnerability. The attributes address features of the building, its site conditions, and the local seismic hazard. Each choice is associated with a numerical value. A simple equation and a lookup table produce an estimate of the dwelling’s damageability—essentially an estimated damage-factor range in a large, rare earthquake—and a letter grade, A to D, with A indicating good expected performance, D indicating poor performance. The document also provides guidelines for the seismic rehabilitation of woodframe dwellings, making it a tool both for diagnosis and treatment of seismic deficiencies.

A related document, ATC-21 (**Applied Technology Council, 1988**, also published as FEMA-154), offers a similar one-page form that an engineer can use to identify buildings of questionable seismic safety. It addresses a wide variety of structure types, and provides for rapid visual screening of buildings for high collapse potential in a large, future earthquake. These two documents are particularly interesting for present purposes in several respects.

1. *ATC-21 and ATC-50 parameterize relevant building features.* Both documents provide rigorous data-collection protocols for rapidly tabulating building features believed relevant to seismic performance. Even if no ATC-21 or ATC-50 form has been completed for a building before an earthquake, they can be used after an earthquake to describe a building with a small, finite number of seismically relevant features.
2. *They have been extensively exercised.* Both forms have been used to create large databases of buildings. ATC-21, for example, has been used to create a database of every building in downtown Portland, OR (Theodoropoulos, as noted in Porter, 2000). ATC-50 has been used to create a database of hundreds of California woodframe dwellings. Extensive training materials are available for both documents.
3. *They represent important experiments waiting to be performed.* The documents encode hypotheses about the seismic damageability of buildings based on their detailed features. The next large earthquake that strike an area with a large number of buildings screened with ATC-21 or ATC-50 will allow engineers to test the hypothetical relationships between detailed features and the building damageability, as long as seismic excitation can be determined for each site. The ATC-21 form and a 2001 draft of the ATC-50 form are duplicated in the electronic appendix of the present paper.

RAPID POST-EARTHQUAKE SAFETY ASSESSMENTS

ATC-20 (Applied Technology Council, 1989, 1991, and 1996) has emerged as the dominant methodology to assess the post-earthquake safety of buildings based on observable damage. The procedures, developed for use by structural engineers and building department officials, provide for both rapid and detailed safety evaluations. For both levels of detail, the engineer completes a brief checklist, and based on the results, posts a placard on the building in one of three colors: red for unsafe, yellow for restricted use, or green for inspected. Under the rapid-evaluation procedure, any one of five readily-observable conditions makes a building unsafe to occupy, including various stages of collapse, significant residual drift, other structural damage, falling hazards, and ground failure. The detailed form allows the engineer to record damage to a variety of building components and to sketch the building or its damaged portions. ATC-20 offers simplicity, speed, and broad applicability; as a consequence it is used by most California cities and other jurisdictions. The electronic appendix of the present paper contains copies of the forms, which can also be downloaded from www.atccouncil.org. They are currently designed for printing and using on paper, as opposed to being completed electronically. Since its introduction, ATC-20 has undergone modifications that are instructive for present purposes.

1. *Allow for judgment.* The authors found it desirable to allow for greater exercise of judgment. Early versions provided only for a yes/no/unknown answer to each condition, a yes statement calling for posting the facility as unsafe. The current form allows for three possible descriptions of each condition: Minor/None, Moderate, or Severe.

2. *More gradations of safety.* In earlier versions, the yellow tag was available in case of uncertainty about whether an unsafe condition existed, whereas the current form allows for restricted-use posting in cases of “localized severe and overall moderate conditions.”
3. *Secondary use to record damage state.* The form now includes a field for the surveyor’s estimate of the building damage state, in terms of the ATC-13 (1985) damage factors.

For purposes of this survey, the present author offers two additional comments based on his own professional experience:

4. *Expect ATC-20 data, but beware of its limitations.* ATC-20 is effective for rapidly assessing the seismic safety of individual buildings with apparent physical distress. However, because it focuses on safety and because inspections are typically called for in cases of obvious structural or architectural distress, it is poorly suited to capture economic losses or to provide unbiased statistical data.
5. *Provide for electronic collection and aggregation.* Paper ATC-20 forms must be collected and transcribed to electronic format—a nontrivial issue. Virtually all cities affected by the 1994 Northridge Earthquake created electronic databases of the ATC-20 evaluations. Despite the common form, the cities used a variety of software applications to compile them, and mapped information from the paper forms to the computer files in dizzyingly diverse ways. The labor involved in compiling these data to a standard format was substantial. A common platform-independent means of completing the form, and another for compiling ATC-20 data into a city’s database and then into county or state databases could greatly improve the efficiency and accuracy of the resulting dataset.

BUILDING-SPECIFIC PERFORMANCE

The **ATC-38 (Applied Technology Council 2000)** project set out to record detailed damage and loss characteristics of buildings located near strong-motion recording sites. Its goal was “to correlate the relationship between recorded ground shaking, ... the observed performance of buildings (both damage and non-damage), and key characteristics such as design date, structural framing type, and number of stories.” The approach employs a six-page survey form (duplicated in the electronic appendix of this study) to be completed by field inspection teams comprised of licensed civil or structural engineers. Survey data address building site, construction data, model building type, features that are expected to modify performance relative to the model building type, nonstructural features, general damage state, nonstructural damage, injuries and functionality, geotechnical failures, recording station information, and strong-motion time-histories and their response spectra. Most of these data would not be available from other sources such as building permits.

The survey form was employed after the 1994 Northridge Earthquake to gather data on 530 buildings located within 300 meters of strong-motion recording sites that were strongly shaken by the earthquake. The field inspection teams comprised two licensed civil or structural engineers, with each survey taking approximately two person-hours per building. Detailed data with photographs are provided in a relational database (several formats). Extensive data reduction and correlation studies are also included. Repair costs are not recorded, but are inferred from the qualitative damage state and an assumed relationship between damage state and damage factor (repair cost as a fraction of replacement cost). The authors reach the following conclusions and recommendations:

1. *Carefully design forms to assist users and data-entry efforts.* Because of problems with data-collection and data entry, the authors revised the forms to make their layout similar to the database. They clarified wording, made changes to avoid opportunities to leave blank spaces, provided fewer but larger spaces

for comments, and expanded the glossary.

2. *ATC-38 can be used to create motion-damage relationships.* Because survey buildings are selected independently of their damage state (i.e., selection is conditioned only on proximity to a strong-motion recording), results are not biased toward greater damage.
3. *Collect large datasets.* The 530 entries gathered after Northridge are too few to create robust motion-damage relationships for most structure types. It seems that thousands or tens of thousands of records are required to discriminate seismic vulnerability by structure type and era of construction, or to discern the effects of other building features.
4. *Compile data from multiple earthquakes.* The authors recommend the use of ATC-38 in future earthquakes to add to the Northridge Earthquake dataset. ATC makes the performance-assessment form available over the Internet, at www.atcouncil.org.

The present author offers the following additional recommendations.

5. *Develop electronic data collection.* The Acrobat performance-assessment forms should be transformed to allow for electronic data entry via portable devices. This will further reduce opportunities to leave empty data fields, and will reduce transcription effort.
6. *Centralize results.* A centralized database should be created to which these records could be posted, either wirelessly from the field or by batches. This will reduce delays between data collection and data availability.

PERFORMANCE OF PARTICULAR STRUCTURE TYPES

Unreinforced Masonry Buildings

Martel (1936) describes an effort designed, in part, to determine “if significant differences in damage [in an earthquake] resulted from differences in the building’s subtype, occupancy, or adjacency to other buildings.” The author examined 1,261 unreinforced-masonry buildings (UMBs) in Long Beach, CA, which were shaken by the March 10, 1933, Long Beach Earthquake, and in a supplementary study, a number of woodframe residences in Compton, CA. The author’s survey drew on the Sanborn Fire Insurance Atlas, supplemented by field checks, to create an initial list of subject buildings. His initial data include number of stories, shape and amount of wall openings (seven types), interior gravity system (four categories), occupancy (six categories), and adjacency (three categories). He used building permits and city tax assessor records to determine the initial value and reduction in value associated with earthquake damage. The author finds that the completeness of these records was aided by the fact that property owners who reported damage received a reduced tax assessment, which probably biased the sample toward high-value and highly damaged structures. These reports provided data on earthquake-related reduction in value for 60% of the subject buildings. Building-permit information provided data on 30% of the subject buildings, and field checks were used for the remaining 10%. Important conclusions include the following.

1. *Multiple data sources* were required to achieve a large, unbiased sample.
2. *Provide incentives.* Incentives to building owners contributed to the extensive data set.
3. *Establish standard definitions.* Consistency between data sources was possible because of the single investigator, single jurisdiction, and focused objectives of the survey. In general this will not be

the case unless the engineering community makes a concerted effort to define and disseminate standard definitions for data and assertions about data.

The present author offers the following addition conclusion.

4. *Definitions of loss matter.* The study reports reduction in assessed value but not the cost of repairs. Reduction in assessed value is taken as the repair cost times the ratio of depreciated building value to purchase price. Consider Martel's example (p. 144) of a property costing \$10,000. Of this amount, \$5,000 represents the replacement cost new of the building (50% of cost), which after 10 years of depreciation is valued at \$4,000, or 40% of cost. If earthquake repairs cost the owner \$800, only 40% of this amount, or \$320, would be assigned to reduction in assessed value. Losses are presented in terms of reduction in assessed value as a fraction of pre-earthquake assessed value, in this case, \$320/\$4,000, or 8%. Today, the loss would commonly be depicted in terms of repair cost divided by replacement cost new, \$800/\$5,000, or a 16% damage factor.
5. *Archive raw data.* Martel's source data contained all the information needed to assess the present-day damage factor, but these data are now lost. The original author's need to summarize and distill for efficient publication is at odds with the needs of later investigators to reexamine the raw data to draw new lessons. This is true for any scientific endeavor. The risk, realized in the present case, is that valuable source data eventually disappear unless carefully archived.

More recently, **Rutherford & Chekene (1990)** and **Lizundia et al. (1993)** present results of a survey of 2,007 unreinforced masonry buildings in San Francisco in the months after the 1989 Loma Prieta Earthquake, using ATC-20 (1989) and a 1-page supplementary damage-assessment form created by the authors. The form is entirely multiple choice other than building location and a box for comments. It includes 62 check-boxes to indicate the nature and location of structural damage, sections to indicate damage state in the ATC-13 (1985) and Wailes and Horner scales, and a single check-box to note evidence of pre-earthquake seismic strengthening. The authors analyze the survey results in Lizundia et al. (1993) to relate building damage state with ground motion and site soil, for purposes of developing a loss-estimation methodology.

Regarding the use of the supplementary damage-assessment form, the authors of Rutherford & Chekene (1990) find that some inconsistent entries arose because of the large number of inspectors, their varied experience, and the difficult circumstances under which they worked, but that the resulting database is "probably the most complete ever collected for a single building type in a given area." They find that observed damage was substantially less than would be estimated using ATC-13 (1985), and speculate on the causes of the difference. In Lizundia et al. (1993), the authors recommend the use of the supplementary damage-assessment form in future earthquakes, but urge that it be coupled with follow-up work to ascertain actual dollar losses and the final course of action taken by the owner. Because of the lack of strong-motion instruments in or near many affected buildings, the authors recommend that instruments be installed in vulnerable buildings to assist in loss modeling, and that geologic conditions at strong-motion sites be investigated. The supplementary damage-assessment form is reproduced in the electronic appendix of the present paper.

Pre-Northridge Welded Steel Moment-Frame Buildings

The SAC Joint Venture performed detailed investigations of damage to pre-Northridge welded-steel moment-frame (WSMF) buildings, in an effort to understand and mitigate brittle failures of the welded connections.

Durkin (1995) describes a SAC postcard survey to gather data on a large number of buildings in the strongly-shaken region affected by the 1994 Northridge Earthquake. A small sample of these buildings is studied in further detail via telephone survey. The postcards gathered summary data on 1,284 buildings, including location, structure type, inspection status, occurrence of damage, an indication of whether structural damage occurred, a qualitative measure of the extent of structural damage, status of repair activities, and a contact person for followup investigations.

From this set, a sample of 150 steel-frame buildings is selected for more-detailed data gathering via a telephone survey. The telephone survey is modest in scope. Answers to its 10 questions are adequate to provide meaningful statistics about inspection and posting status, nature of inspections, summary information about the building (age, square footage, and height), general extent and nature of physical damage and repairs, and basic yes/no information about injuries and loss of use. The one-page survey form is included in the electronic appendix of the present paper. Future studies could be improved by publishing raw data (important for verifying authors' conclusions and for adding data from future studies), and by asking respondents whether they would be willing to answer additional questions from later researchers.

Another SAC publication, **FEMA 352 (SAC Joint Venture 2000)**, is an exemplar of a data-gathering procedure designed to inform a nuts-and-bolts-level structural-engineering decision process. It specifies data-gathering, analysis, and reporting procedures for evaluating the safety of welded-steel moment-frame (WSMF) buildings, and for determining required rehabilitation measures. The data-gathering aspects of this study are extraordinary in that they document performance at a level of detail similar to studies of laboratory specimens. An appendix of the report contains a form (duplicated in the electronic appendix of the present study) that details the geometry and performance of individual beam-column connections.

Using this form, the surveyor notes information about the site, location of the connection within the building, and precise details of the deformation and physical damage to welds, plates, bolts, beam, and column elements. Damage is characterized using a system of 23 types of damage, in which each damage type is defined in pictures and words in terms of the connection element damaged, the location of the damage within the element, and the severity of the damage. Surveyors compiled complete data on 2,238 connections—damaged or undamaged—in 31 frames of six buildings.

In companion studies (**SAC Joint Venture 1995**), structural engineers estimate the structural demands imposed on each connection in a variety of terms (elastic beam-end moments, inelastic rotation, and interstory drift). The structural demands can then be compared with the observed performance of each connection. The most valuable features of this study, which should be emulated in future investigations of the performance of structure components include:

- Clearly defined data-gathering procedures, including objectively-defined performance metrics, depicted both in words and in pictures;
- A large sample set of subjects, gathered without apparent bias with respect to any particular performance metric or conclusion, with published raw data;
- The approximate excitation experienced by each subject; and
- Oversight by a panel of experts specializing in all the relevant fields.

Future studies would benefit from more information about the seismic excitation of the subjects, which requires a denser network of strong-motion instruments in buildings.

Woodframe Buildings

McClure (1973) presents results of a detailed study of 169 single-family dwellings in the epicentral region of the 1971 San Fernando earthquake, all of which were subjected to peak ground acceleration of 0.25g to 1.0g, and almost all of which experienced damage in excess of \$5,000 (approximately equivalent to \$20,000 in 2002). The author's objective was to use the earthquake experience of these dwellings to review the Federal Housing Administration's (FHA) Minimum Property Standards (MPS; U.S. Department of Housing and Urban Development 1971), which address single-family dwelling location, site planning, engineering, structural design, and construction.

He desired to observe the effects on seismic performance produced by differences in rise type (one story, one-and-two story, two-story, one-and-two-story split level, and other), seismic excitation (shaking only, and shaking and ground failure), soil condition (four types), and site grading (four types). He selects a non-random sample of dwellings to permit "an intensive study of the performance of structural and nonstructural and nonstructural elements across the various categories of interest." He refers to the process as quota sampling. The sample is limited to single-family detached dwellings built since 1950.

The author designed a survey form, modified and field tested it, carried out with the assistance of "graduate civil engineers under the direction of licensed structural engineers," and analyzed the results. The survey form includes approximately 200 questions. (It is duplicated in the electronic appendix of the present study.) The survey appears to have been mostly multiple-choice. It includes many qualitative or subjective questions such as "interior finish damage," with possible answers "none, slight, moderate, severe, total, or not applicable." Qualitative definitions of each damage state are provided in the text. Several conclusions are relevant to the design and conduct of surveys.

1. *McClure's (1973) survey is informative of the effects of detailed features.* The author discerned effects on seismic performance from detailed structural, architectural, and site features, and made recommendations for revisions of the building-code-like MPS.
2. *Quota-sampling reveals the trees but conceals the forest.* The author found that quota sampling is necessary and valuable for understanding the effects of the study characteristics, but because of the non-random nature of the sample, could not draw statistical inferences about the universe as a whole.
3. *Define damage states.* For consistency and clarity, define damage states in detail.
4. *Test and revise survey forms.* The author tested and revised the survey form three times before performing the complete survey.
5. *Publish the survey form and the raw data.* McClure's survey form is not included in the document, but his raw data are provided in a compendium.

Schierle (2002a) examines woodframe dwelling losses of the 1994 Northridge earthquake. One important objective was to create seismic vulnerability functions—relationships between earthquake repair costs and shaking severity—for six categories of dwelling. Dwellings are categorized by plurality (i.e., single-family or multiple-family) and era of construction (pre-1941, 1941-1976, and 1977-1993). Repair costs are expressed in terms of the damage factor, i.e., as repair cost divided by an estimate of replacement cost, and in terms of cost per square foot of floorspace. Shaking severity is parameterized in terms of peak ground acceleration taken from TriNet maps, discretized in three levels: less than 0.30g, 0.30-0.60g, and greater than 0.60g. The author draws on three primary data sources for repair cost and dwelling category: (1) a file of damage-factor estimates for 45,702 buildings, created by City of Los Angeles Building Department officials during rapid post-earthquake field investigations, (2) Los Angeles County Tax-Assessor files, which

provide the assessor's record of square footage, number of dwelling units, and year built; and (3) building-permit applications for 1,230 buildings. These provide the contractor's valuation of repair work and describe the work to be performed. For large projects, building departments perform rough, independent cost estimates to ensure that the contractor's valuation is reasonable, so one can think of these permits as reasonably reflecting actual construction cost. With smaller projects, some contractors may underreport valuation for tax-avoidance purposes (Schierle, 2002b).

Of particular interest in this study are the author's comparisons between building-specific costs based on rapid loss estimates and costs from building permits. (The translation from damage factor to repair cost is made by assuming a common per-square-foot replacement cost.) For individual structures, the average absolute discrepancy between loss estimates ranges from 40% and 300%, as a fraction of the contractor's stated repair-cost estimate, for a given dwelling category and range of shaking severity. In aggregate, the two sources agree better, with the sum of repair costs for a large number of buildings agreeing within 5% to 50%, depending on dwelling category and shaking level. One can draw at least two lessons from this study about the utility of public records for the creation of seismic vulnerability functions:

1. *Adequate data.* Public loss records of the type described here provide adequate data to create mean seismic vulnerability functions that distinguish the effects of era and general type of construction.
2. *Reasonable agreement between two types of data.* Seismic vulnerability functions based on large numbers of rapid loss estimates generally agree in the mean with seismic vulnerability functions created using the repair-cost valuation stated in contractors' permit applications.

REGIONAL LOSSES

US Coast and Geodetic Survey (1969) deals with efforts to collect and analyze earthquake data for use in developing earthquake-insurance alternatives. Chapter 3 of volume 1 is particularly relevant here. Its author, Frank E. McClure, presents "a program of study and research in gathering earthquake damage statistics, concerning the dollar value loss, by class of construction, in terms of earthquake resistance." He reports on a study of approximately 1,139 buildings that were reported as damaged by the M7.6 Kern County earthquake of July 21, 1952, and its aftershocks.

McClure's objective is to estimate the fraction of all structures, by class of construction and "amount of lateral bracing," that were demolished, repaired, or undamaged as a result of the earthquake. His data sources include a private, unpublished report of 362 buildings that had suffered damage; building permits from the City of Bakersfield Building Department; Sanborn Map Company maps from 1952-1953; and a study by Steinbrugge and Moran (1952) of 78 unreinforced masonry buildings. McClure lacks the number and value of woodframe and light-metal buildings exposed to damage, so he is unable to determine the fraction of these buildings that were damaged. He does not attempt to create motion-damage relationships, but merely to estimate the losses should the 1952 events recur in 1969. None of his sources provide information on shaking severity. McClure offers several pieces of advice for future investigations:

1. *Plan for investigations before the earthquake.* A single government agency should be responsible for performing future earthquake investigations. The agency should establish objectives; liaise with engineering professional societies; use reconnaissance teams of structural engineers, seismologists, engineering geologists, building officials, and architects; develop and provide reference materials

and data-gathering worksheets; and provide geological maps and maps that indicate building layout and structure type.

2. *Set up a base office.* After an earthquake, teams should meet at the base office to receive housing, transportation, credentials, messages, research assignments, and other logistical necessities. The base office would also establish a system by which buildings are unambiguously identified. (Note that EERI's Post-Earthquake Investigation Field Guide provides for such a base office.)
3. *Create field worksheets and a central data repository.* Gather data with brief worksheets that use standard, well-defined terminology for degree of damage, class of construction, and occupancy. The data should be compiled along with data from tax-assessor, city and county public works, building departments, and other public entities.
4. *Perform second-round, value-loss investigations.* Buildings initially identified as having experienced non-negligible damage should receive an on-site follow-up investigation by an appraiser, architect, experienced insurance claims-adjuster, and structural engineer, to estimate the economic loss.

Note that in discussing maps that indicate building layout, McClure refers to now-defunct Sanborn Maps. The value of these maps was that they were publicly available, provided standardized building configuration and construction information, and had wide geographic coverage. Despite the demise of the Sanborn Map Company, modern near-equivalents exist. Comerio (2002) points out that several city planning departments maintain geographic information systems (GIS) that contain much of this data, albeit in nonstandard formats and nonstandard ontologies that are idiosyncratic to each city.

EERI could promote the development and use of a standardized system. One possible route would be to partner with the private sector, perhaps promoting a data-standards entity such as is common in high-technology development, to address data standards for building information. Starting points do exist: the city of Glendale, California, for example, maintains such a GIS database.

The National Research Council's **Committee on Assessing the Costs of Natural Disasters (1999)** examines the question of compiling comprehensive post-event loss information from natural disasters. The authors argue that although governments, businesses, and private entities have an interest in accurate loss data, no comprehensive disaster loss information is available either from public or private sources, and that no standardized estimation technique or framework exists for compiling these data. The authors recommend that U.S. Department of Commerce's Bureau of Economic Analysis be made responsible for compiling information on losses at a societal level. The authors do not suggest particular data-collection protocols to be used, but they do detail the categories of desirable information, under three general headings: direct losses, indirect losses, and indirect gains.

For compiling direct losses, the authors suggest a grid of 16 general types of loss (rows in the table) and five categories of entity initially bearing the loss (columns). Types of direct loss include damage to various kinds of buildings, contents, landscaping, vehicles, agricultural products, cleanup and response costs, loss-adjustment costs, living expenses, fatalities and injuries. (The complete table for direct losses can be found in the electronic appendix of the present study.) Indirect losses include wages, sales and profits lost because of business interruption at damaged facilities or resulting from infrastructure failure; input/output losses to businesses because of business interruption suffered by suppliers or customers; and ripple effects, i.e., reduction in economic activity triggered by business closures or cutbacks. Indirect gains include economic activity displaced from the affected region to areas outside of it, and the ripple effects thereof; income gains outside the affected region because of cost inflation resulting from disaster-induced shortages; and the economic activity associated with repairs and cleanup.

BENEFIT OF SEISMIC REHABILITATION

Onder Kustu, the author of **ATC-31 (Applied Technology Council 1992)**, set out to assess the benefit of seismic retrofit of buildings. To achieve his ends, the investigator needed a statistically significant and representative sample of information about retrofitted buildings, including four basic parameters for each building: shaking severity, structure type, structural retrofit, and damage factor. (He could then assess the benefit of seismic retrofit by comparing the apparent vulnerability of retrofitted buildings with the judgmentally derived ATC-13 vulnerability functions, which he considered to represent the unretrofitted case.)

His data source is a survey of members of the Structural Engineers Association of California (SEAOC), along with data collected by SEAOC members, other practicing engineers and building departments. These data were collected using a 2-page paper survey form containing approximately 51 data fields. Shaking severity is expressed in terms of MMI, using the building's location per an approximately 4-km grid. Structure type is described in terms of 15 categories of "vertical" system (i.e., elements of the lateral-force-resisting system and gravity system other than floor and roof components) following the ATC-14 and ATC-21 taxonomy, eight categories of "horizontal" system (floor and roof elements), and three foundation types. Structural retrofit is described in terms of 18 categories. Damage is described by ATC-13's seven qualitative damage states, which are used to infer damage factor. The database contains information about 113 retrofitted unreinforced masonry buildings and 43 concrete tilt-up structures affected by the 1987 Whittier Earthquake or the 1989 Loma Prieta Earthquake.

The author reaches a number of conclusions relevant to the present study. First, he finds that inadequate data have been gathered to reach firm conclusions either about the benefits of seismic retrofit at MMI VI shaking levels, or about the benefits of competing retrofit methods. He finds that some survey fields were erroneously filled because the respondent did not understand the structure type classification system. The implications of these observations are that:

1. *Large datasets are required.* Strong conclusions about seismic vulnerability require thousands of samples to assure statistically significant subsets of data.
2. *Test survey forms.* Survey forms must include detailed definitions, and must be tested before use.

The author offers three additional recommendations that are relevant here:

3. *Modify standard post-earthquake damage-assessment forms,* used by government agencies such as FEMA and OES, to include "Data on retrofit criteria and methods, ... general information on the structural characteristics of the buildings, and expanded descriptions of type and extent of damage."
4. *Enlist the assistance of building departments* to identify and track seismic retrofitting projects as part of their permitting process. (If this recommendation is followed, special effort must be made to ensure that actual construction costs are recorded and distinguished from other costs such as tenant improvements.)
5. *Use ATC-31 in the future.* Projects similar to ATC-31 should be undertaken following future earthquakes, in order to assess the benefits of seismic retrofit.

NONSTRUCTURAL COMPONENTS

MCEER NONSTRUCTURAL DATABASE

Kao et al. (1999) present a database of 2900 instances of damage to nonstructural components. The database includes information about the earthquake, the site location, the nature of the facility, the shaking severity in terms of ground and floor accelerations, the overall facility damage factor, the affected component, a text description of the damage, the impact of the component damage on the facility performance, and a reference to the source from which the information is drawn. It includes a few forms and queries for summarizing, viewing, printing, and appending records. The database is actually a secondary source, a summary of information drawn from 103 books, reports, and periodicals about 52 earthquakes between the 1964 Anchorage, Alaska Earthquake and the 1999 Quindio, Colombia Earthquake. The database is available online in its published, 1999 form, in Microsoft Access format, from the Multidisciplinary Center for Earthquake Engineering Research.

The database provides a valuable survey of failure modes to which a variety of nonstructural components are prone. Neither component names nor performance descriptions are standardized, so the user must be thorough in querying the database for information. For example, 11 synonyms for air-conditioning equipment appear in the database. The database is not intended to be an unbiased sample of equipment performance, and so cannot be used to calculate failure probabilities as a function of shaking severity.

KOBE CONTENTS-DAMAGE SURVEY

Saeki et al. (2000) present data on household property loss resulting from the 1995 Kobe earthquake. The data come from 965 questionnaires returned by insurance-company employees living in the Hyogo and Osaka prefectures. The questionnaires ask about damage to the building itself and damage to household property. Building-damage data include address, building size (1-2 stories, 3-5 stories, and 6+ stories), and degree of damage to the building (“total loss,” “half loss,” “partial loss,” and “undamaged”).

Questions about household property address ownership of and damage to 10 categories of contents: six categories of durable possessions such as furniture, appliances, and electronics; and four categories of non-durables such as curtains, tableware, and clothing. In the case of durable possessions, the authors sought household damage ratios: number of durable possessions in each category that were damaged, divided by the total number possessed. In the case of non-durables, where counting damaged items was more problematic, the authors define the damage ratio as the number of households with some loss in the category, divided by the number of households responding.

The authors performed a regression analysis, comparing damage ratios with seismic intensity (JMA scale) to create a fragility function for each category of household content. The authors detail their content-categorization system, and provide the parameters of the fragility functions. The required brevity of the paper prevents the authors from providing the questionnaire or the raw data. The electronic appendix of the present paper contains a copy of the content-categorization system.

EQUIPMENT-SYSTEM RISK EVALUATION

Johnson et al. (1999) offer a tool to estimate and manage the seismic reliability of equipment systems, based on a detailed examination of the system components, and using a simplified logic-tree analysis of the system. The methodology produces a “seismic score” for an overall equipment system, which relates

to the annual probability of the equipment system failing to perform its required function. Individual equipment components are assessed using a set of standard, 2-page, multiple-choice forms, one for each of 37 component types. The forms allow the analyst to estimate the seismic reliability of the component, considering the type of component, the seismic hazard at the site, the location of the component within the building, and its installation conditions such as adequacy of seismic restraint and potential for interaction with other components. The scores are then used to assess the reliability of the overall equipment system.

Although this study provides a method to predict risk prior to an earthquake rather than performance after an earthquake, it is nonetheless valuable for the present study in the same way as ATC-21 (Applied Technology Council 1988) and ATC-50 (Applied Technology Council 2001 draft). It offers a detailed, formal structure for inventorying building equipment, for indicating their installation conditions, and for depicting their relationship to overall system performance. It offers a pre-established taxonomy of components and of common installation conditions and deficiencies. The materials provided in this report could be adapted to post-earthquake surveys by adding fields to each form to indicate observed performance, e.g., operational or non-operational, with the surveyor circling observed deficiencies and observed causes of failure.

LIFELINES

PIPELINES

Lund and Schiff (1991) present a database for recording and compiling pipeline damage records. The database is composed of records, one record for each pipe failure. Each record consists of 51 data fields, indicating the associated earthquake, the pipeline owner, pipe break location, soil condition, details of construction and installation, and nature of the break. The database, which contains information about 862 pipe breaks in the 1989 Loma Prieta earthquake, is defined to facilitate appending pipe-break data from future earthquakes.

The authors recommend its use in future earthquakes, but advise that such work can only be performed several months after the earthquake has occurred, since pipeline breaks can take some time to be discovered and repaired. The authors also recommend coordinated collection of pipeline damage data, to minimize redundant data-gathering efforts. They acknowledge that the value of the database would be enhanced by detailed descriptions of the systems suffering damage. (Since the subject paper was published, the use of geographic information systems by utility districts has become much more widespread.) Finally, the authors recommend the use of their methodology and database in future earthquakes.

It is noteworthy that the authors archived their database in two common formats—DBF and comma-and-quote text file—both of which are readily accessible today, independent of the software used to create them, and likely to remain accessible for some time. Furthermore, their report and database are available online, distributed by the National Information Service for Earthquake Engineering (NISEE) at University of California, Berkeley. The online version of the report appears without its associated figures and tables, although these should be visible in the paper copies archived at various locations listed in the report.

BRIDGES

The California Department of Transportation maintains a log of bridges on state highways (**Caltrans 2002**), a database of state bridge sufficiency ratings (**Caltrans 2001a**), and a database of local bridge sufficiency ratings (**Caltrans 2001b**). The log of bridges shows bridge location (district, county, city, route and postmile), material and structural system, bridge length, width, number of spans, year built, years of widening or extension, and current operational status. The sufficiency ratings tables show location, material and structural system, year built, number of lanes, average daily traffic, the number of miles a vehicle would have to travel if the bridge were closed, and condition of the deck, superstructure, and substructure. None of the tables indicate latitude and longitude, seismic rehabilitation, or any direct indicator of expected seismic performance. They do, however, offer a basis for consistent identification of bridges that experience strong motion and damage.

Basoz and Kiremidjian (1998) present results of a study of bridge damage data from the 1989 Loma Prieta and 1994 Northridge Earthquakes. Their objectives were to compile, review, and analyze bridge damage data, and to correlate observed damage with structural characteristics, ground motion, and repair cost. They present a set of fragility functions for a number of categories of bridges, relating the probability of reaching or exceeding certain damage states as functions of peak ground acceleration.

The authors' fragility analyses are beyond the scope of the present paper, but it is worthwhile to describe the databases they compiled. The authors created two databases, one for each event. Each database contains five data types: structural characteristics, bridge damage, repair cost, shaking severity, and soil characteristics.

- *Structural characteristics.* These are compiled from Caltrans' Structural Maintenance Systems (SMS) database. Their characteristics include abutment type, number of spans, type of superstructure and substructure, bridge length and width, skew, number of hinges at joints and bents, abutment and column foundation types, and design year. The authors create a taxonomic system based on single- vs. multiple-span construction, abutment type, column bent type, and span continuity. These features produce 21 categories of concrete bridge. The bridge taxonomy is copied in the electronic appendix of the present paper.
- *Damage states and repair cost.* The authors describe bridge damage states in both descriptive terms and in terms of ranges of damage factor (repair cost as a fraction of replacement cost). Damage descriptions were compiled from Caltrans reports, which characterize damaged bridges in one of two damage states for Loma Prieta (minor or major) and four for Northridge (minor, moderate, major, or collapsed). The damage descriptions were subjective, and no guidelines existed to define them, so in collaboration with Caltrans engineers, the authors developed damage-state definitions (Basoz and Kiremidjian 1996). They compiled repair costs from Caltrans' supplementary bridge reports, and calculated damage factors by assuming a bridge replacement cost of \$90 per square foot of deck.
- *Shaking severity and soil characteristics.* Shaking severity for the Northridge Earthquake is determined from maps of peak ground acceleration (PGA). Severity for Loma Prieta is estimated using seismic attenuation relationships. The authors do not discuss the source or their use of soil data.

The authors find that the databases on which they rely contain occasional discrepancies. Redundant databases containing structural characteristics differed frequently (15%) in abutment type, and occasionally (2 to 3%) in design year and skew. These discrepancies were corrected by reference to structural drawings. These changes in some cases materially affect the resulting fragility functions. More serious are discrepancies in shaking severity. Estimated ground motions in Loma Prieta differ substantially from

recordings at strong-motion instruments. There are also substantial differences in shaking severity between two maps of Northridge PGAs. These differences necessitated the authors' developing redundant fragility functions, one set for each map. Finally, as noted above, the authors find that Caltrans' damage-state descriptions are subjective and inconsistently applied, hence the need for their new damage-state definitions.

INDUSTRIAL EQUIPMENT

Yanev (1990) summarizes an extensive database of the observed seismic performance of industrial equipment and nonstructural components. The database was developed for the Electric Power Research Institute (EPRI), and compiled from surveys by engineers of EQE International (now ABS Consulting). The focus of the database is on facilities related to electric power, including power plants, electrical-distribution substations, oil refineries, and natural-gas processing and pumping stations. There are also extensive entries related to the earthquake performance of water-treatment and pumping facilities, large commercial facilities, hospitals, and conventional buildings. By 1990, the database reflected equipment performance at more than 100 major facilities, many smaller facilities, and hundreds of buildings that experienced strong motion (typically peak ground acceleration of 0.15g or greater). Surveys at that time included experience in 42 events since the 1971 San Fernando Earthquake.

Database entries regarding equipment include an equipment description (using a formal, internally developed taxonomic system); photographs; in some cases manufacturer's literature for some components; information about the seismic installation (i.e., fixity and connection to other components); seismic excitation experienced; and a description of the source and nature of damage. Damaged and undamaged components are reflected in the database. There are also notes and audiotaped interviews of facility engineers describing the facility experience in the earthquake, along with other records such as log books, damage reports, maps, schematics, and drawings. No formal survey form was used to compile the database. Rather, a format was imposed after the fact. The database is licensed by ABS Consulting of New Hampshire.

CASUALTIES

Seligson et al. (2002) describe their efforts to gather "comprehensive Northridge Earthquake casualty statistics ... to refine current engineering-based casualty model results to make them more meaningful to the engineering and medical communities for emergency response and planning purposes." A portion of that work involved performing 1,800 random-digit telephone interviews of people in the region affected by the Northridge earthquake. They find that 8% of interviewees reported that an injury of some kind occurred in their household. Each interview resulted in knowledge of the geographic location, injury severity, and injury mechanism in terms of the physical damage to the building or its contents that caused the injury. In another effort, they thoroughly surveyed coroners and hospitals for earthquake injury and fatality data. These data also show injury mechanism. The authors do not publish the data-gathering procedures involved in the telephone interview, although **Bourque et al. (1997)** and **Shoaf and Peek-Asa (2000)** discuss disaster-survey methods, random-digit telephone surveys and population-based surveys of hospitals and morgues.

To facilitate their surveys, the authors developed a standardized classification scheme for earthquake-related casualties (**Shoaf et al. 2000**). The scheme includes demographic data, cause and severity of injury, treatment and costs, activity at the time of injury, location, characteristics, and

damage of the facility in which the injury occurred. Using this classification scheme in their surveys, the authors find that deaths are primarily associated with collapse or partial collapse. The fraction of occupants killed in a collapsed portion of a building is typically less than 1.0, owing to voids remaining in the collapsed structure. The fraction varies by structure type. Survey methods developed by these authors (and the data they gathered from the several large earthquakes since 1994) can be used to inform future casualty data-gathering methods and to improve engineering models and public-health planning for future earthquakes.

HUMAN BEHAVIOR

Bourque et al. (1994) present a study of human behavior during and immediately after the 1989 Loma Prieta Earthquake. The Loma Prieta study examines what people did during the earthquake, their use of broadcast media, and whether and why they evacuated their homes. The authors performed a telephone survey (called random-digit dialing, to indicate that respondents are selected at random) of 656 people throughout the San Francisco Bay Area. The survey was performed 224 days after the earthquake, took approximately 30 minutes per respondent, achieved a response rate of 70 to 81 percent, and focused on regions shaken at mean Modified Mercalli Intensities of 6.7 to 7.9. The survey questions address several particularly interesting questions: How do location and companions influence one's efforts to avoid harm? Do people seek information from broadcast media, and how does that effort vary depending on location and companions? Who leaves their homes and why? The answers are relevant to safety planning, use of the media to inform the public, and programs to assist displaced persons.

The authors present a variety of interesting results that demonstrate the efficacy of the survey. For example, they found that many fewer people evacuated their homes than reported damage or the loss of utility service, and of those who evacuated, many left their homes because they were upset, rather than because of damage or utility failure. The authors point out some of the limitations of random-digit dialing, most notably that the very people most likely to be underrepresented in such a survey, such as people in single-room occupancy hotels at the time of the earthquake, might have been disproportionately dislocated by the earthquake. The authors hope that comparison of survey data with census information would help to assess the extent of under-representation of groups like this in the survey. The authors also note that the survey instrument has evolved over multiple applications. It had been adapted by questionnaires by Bourque et al. (1973), Turner et al. (1986), and included modifications from that of Goltz et al. (1992) to explore posttraumatic stress; to identify location more precisely; and to address unique details of the earthquake (year, name, etc.). The survey instrument for Loma Prieta is presented for the first time in the electronic appendix of the present study. The resulting database is available for download at NISEE's Loma Prieta Data Archive (1991).

BUSINESS DISRUPTION

Tierney (1997) and **Tierney and Dahlhamer (1998)** describe surveys of disaster-related business impacts of the 1993 Midwest floods and the 1994 Northridge Earthquake. In both cases, a 20-page questionnaire covers eight general topics: business characteristics, nature of physical damage, lifeline service interruption, business closure, business relocation, insurance and disaster-assistance programs, disaster preparedness, and losses. The sample size was in the thousands, with response rates of 23% (Northridge) and 50% (Des Moines) producing 1,100 responses in both cases. The authors summarize the survey methodology, which involved an initial mailing of surveys and telephone follow-ups.

The authors find that postcards and second-reminder mailings, common features of mail-survey

research, were unnecessary for their purposes. The surveys are informative of the extent of business interruption, particularly with respect to lifeline service interruption, a crucial issue for evaluating societal costs and benefits from lifeline seismic rehabilitation.

The Northridge survey indicates poor earthquake preparedness and limited effectiveness of the measures that businesses had taken. The surveys are also informative of indirect effects: loss of material flow into and out of the business and loss of customers are common reasons cited for business interruption. The authors find low utilization of insurance or government programs, leaving open the question of why, a question that the questionnaires do not address. The authors call for additional research to explain this fact, and to explore the significant relationship between business vulnerability associated the size of the business. Although the authors summarize the survey results, the raw data are unpublished. The questionnaires however are published for the first time in the electronic appendix of the present study.

Surveys such as those described by Tierney (1997) and Tierney and Dahlhamer (1998) shed light on an important issue in earthquake-loss evaluation. The authors cite an estimate that 23% of Northridge Earthquake losses were attributable to business interruption. The fact that businesses' poor level of preparedness harmed their performance suggests an opportunity for significant loss-reduction in future events, and argues for better understanding of business owners' preparedness decision-making.

INSURANCE

Insurance-loss information is valuable to earthquake engineering for at least three reasons. First, insurance losses are indicative of underlying physical damage and can be used to inform engineering damage models. Second, insurers and regulators use past loss data to make important decisions about ratemaking, reinsurance, and reserves, decisions that earthquake engineers are often called upon to assist. Third, government can become the insurer of last resort, meaning that earthquake engineers are often called upon to use insurance-loss information to assist in public-policy planning.

Loss data are available to varying degrees from three sources: primary insurers, who collect claims data at the level of individual policies; insurance regulators such as the California Department of Insurance, who gather summary data from insurers; and from insurance industry groups such as the Insurance Services Organization, who collect and publish aggregate industry-wide loss data. The first and the last are considered here.

PROPERTY INSURERS

Property insurers each maintain their own proprietary databases of insured property and claims experience. These databases are typically developed internally, comprise a combination of paper and electronic files, are idiosyncratic to each insurer, and are usually available only to company staff or to consultants hired by the insurer for loss analysis. Some researchers do manage to acquire insurance information, so it is worthwhile briefly to discuss these data. The following observations are based on the author's experience with approximately ten insurers' earthquake-insurance databases.

Insurers maintain two basic types of earthquake-insurance information: policy data and claims data. The policy database contains information about all of the insurer's policies in a geographic area that are exposed to loss. Policy information is often provided by the insured to the insurer in an office interview, by phone, mail, or the Internet, without an inspection of the insured property. Policy data

typically contains, among other fields:

- Policy number.
- Location. For residential properties, this is typically the address of the insured property. Commercial insurance covering multiple sites may not indicate the location of each site.
- Policy limits. This is the maximum amount the insurer will pay. Separate limits are typically expressed for buildings, ancillary structures, contents, and time-element losses, i.e., additional living expenses or business interruption. Limits are not necessarily the same as the value of the insured property. Content values can be much less than content coverage, and building replacement costs can significantly exceed building coverage.
- Deductible, typically as a percentage of policy limits. Deductibles can apply to each coverage separately or to the combined loss.
- Structure type. Nonstandard systems for classifying structure type are common.

The claims database contains information about amounts paid to insureds after particular earthquakes. Information on claims paid is typically provided by a claims adjuster, and includes the policy number, site location (often but not always), and amount paid, sometimes but not always broken out by coverage (primary structure, ancillary structures, contents, and time element). Claim amounts can differ substantially from the actual cost of repairs, aside merely from the deductible. Claim payments can reflect payments made to repair pre-existing damage, because of a lack of knowledge on the part of the insured or adjuster. Payments can fail to reflect hidden earthquake-related damage, invisible at the time the claim is paid. Also, insurers often pay for repair work that would otherwise not be performed in the absence of insurance. For example, they will pay to repaint an entire room when only one wall is damaged; this is the so-called *line-of-sight* issue. Claims adjusters sometimes round-up claim amounts to forestall customer complaints. Finally, demand-driven cost inflation (*demand surge*) can cause significant increases in repair costs after major catastrophes.

PROPERTY CLAIMS SERVICES

Summary estimates of insurance-industry catastrophe losses are more readily accessible than insurers' policy and claims databases. The main source of industry-wide catastrophe loss experience in the United States is the Property Claim Services (PCS) of **ISO (2002)**. PCS considers a catastrophe to be an event that causes "\$25 million or more in direct insured losses to property and that affect a significant number of policyholders and insurers." For each such event, PCS estimates the total insured property loss in five categories: fixed property, building contents, time-element losses (additional living expenses and business interruption costs), vehicles, and inland marine (diverse goods and properties, typically in transit).

PCS creates its loss estimates by polling a subset of insurers and then extrapolating to an industry-wide figure using the polled insurers' market share and using PCS' estimate of the number and type of structures, by ZIP Code, across the United States. PCS typically issues a number of loss estimates for each catastrophe, starting with an initial "flash" estimate within hours of the event, and then one or more times in subsequent days and weeks with follow-up estimates as claims data become available to the polled insurers.

PCS maintains a proprietary database of these losses since 1949, which it calls its Catastrophe History Database. The database contains date of occurrence, state(s) affected, type of catastrophe (10 categories), amount of loss (estimated payment, average payment, number of claims, and total dollars), and type of estimate (preliminary, resurvey, or final).

AGGREGATING AND INTEGRATING SURVEY DATA

INTEGRATING SAFETY ASSESSMENTS WITH PLANNING AND RECOVERY

Cities and other jurisdictions use the ATC-20 methodology to determine the seismic safety of buildings, and to prevent or limit access to unsafe or potentially unsafe structures. Once a building is posted with an ATC-20 evaluation however, there remains the problem of designing, approving, and performing seismic repairs or demolition. To address this problem, Accela, Inc., has developed the **Emergency Response System (ERS, Accela, Inc. 2002a)** and **Kiva Development Management System (DMS, Accela, Inc. 2002b)**. These systems comprise computer hardware and telecommunication and database software that integrate ATC-20 evaluation with land management, construction permitting, and inspection. ERS allows city inspectors to perform safety evaluations using palmtop devices wirelessly connected to a central GIS-enabled database. The GIS feature reduces the potential for ambiguity over the precise location of inspected buildings—a significant problem in cases where a single structure has multiple addresses. City engineers can then use the same database and the DMS to record and track building permit applications and construction inspections, producing an end-to-end record of damage, safety assessment, loss, and restoration.

The City of Glendale has adopted ERS and DMS as part of a broader data plan. According to a city official (Fabbro 2002), the intent is that all non-private disaster and recovery data will be permanently available via the Web for research purposes. To achieve a durable dataset, the data are stored in as generic a form as possible, so that changes to software applications do not hinder access. The city has a GIS system that shows parcel boundaries, and building outlines, and will eventually show UBC construction category for every structure (this is the potential replacement for Sanborn maps alluded to above). It is currently in the process of adding scanned images of all construction drawings that accompany permit applications, both past and future, which will facilitate the study of seismic performance of more-detailed structure types.

AGGREGATING REGIONAL SAFETY, DAMAGE AND LOSS DATA

A study of the Northridge Earthquake by **EQE International, Inc., and the Governor's Office of Emergency Services (1995, 1997)** represents perhaps the most-thorough effort ever to document one of the most-costly natural disasters in U.S. history. It summarizes efforts to collect a centralized, exhaustive database of the effects of the 1994 Northridge Earthquake. The data contained in these reports address the seismological and geotechnical aspects of the earthquake; the characteristics of the building stock exposed to strong motion; building damage data including ATC-20 safety evaluations and repair-cost estimates; coroner data on earthquake-related fatalities; relocation and injury data from cities, the Red Cross, and the Salvation Army; and insurance losses reported by the California Department of Insurance. The two volumes of this study present a wealth of summary data in tabular, graphical, and map format, along with extensive analysis of the information.

Because of privacy considerations, restrictive-use agreements, and the use of proprietary information, the underlying raw data are not provided with the report. The California Governor's Office of Emergency Services (OES) offers to make the raw data of Northridge available. However, because of privacy concerns, OES does not provide personal information and conceals detailed facility locations using generic, nearby locations (Kehrlein 2002). These precautions, though necessary, inhibit data-checking and follow-up data gathering. Furthermore, the format of the Northridge data is also

absent from the report, which limits the use of the database as a pattern for future data-gathering.

The authors make a number of relevant conclusions regarding the data-collection effort. Among these are:

1. *In some counties, tax-assessor data can provide crucial inventory data.* To understand the damage, one must also establish the quantities and characteristics of the building environment exposed to damage. The authors identify six desirable pieces of information for each building in the affected region: (1) street address; (2) construction and material type; (3) height or number of stories; (4) age or construction date; (5) use or occupancy type; and (6) total square footage. For some counties, tax-assessors files can provide these data for much of the built environment. Construction and material-type information in tax-assessor files can be of limited reliability.
2. *Assessor information is imperfect or undesirably summarized.* The comprehensiveness of tax-assessor data vary substantially between counties. Few publicly owned buildings appear in assessors' databases. Some information on structure type was available for Los Angeles County (five categories including "other"), but none for Ventura County. Number of stories was available for commercial buildings in Los Angeles County, but summarized by height ranges that differed from the authors' preferred grouping.
3. *Census data are unreliable in terms of age distribution of buildings.* The authors' comparison of assessor data and the Census of Housing indicates that the census modestly underestimates the total number of residential buildings, and exhibits a strong bias in terms of age of dwellings. Any use of census data for inventory purposes should therefore be checked using assessor files, field surveys or other sources.
4. *A large, detailed, systematically organized database of building damage can be collected.* Building-specific damage data were of two types: ATC-20 safety-assessment (tag color) of 115,000 buildings, rough estimates of dollar damage for 97,000 buildings, and of damage factor for 72,000 buildings. After filtering for buildings whose structure type, use, year built, and geolocation could be determined, these figures are 85,000, 84,000, and 63,000, respectively. The authors attribute the unprecedented damage database to five factors: the earthquake occurred in a highly urbanized region; the earthquake was large; the affected region was densely instrumented with strong-motion recording devices; government agencies were prepared to use new technology to gather data for decision-making purposes; and advances in hardware and software made collection and depiction of large datasets practical.
5. *Damage data are far from exhaustive and take a long time to accumulate.* Damage information was collected on 100,000 buildings, yet the insurance industry reported more than 350,000 claims. In addition there were an unknown number of uninspected, uninsured buildings. Dollar damage estimates are based on cursory inspections, many of which did not include access to the interior of the structure, and which did not include furnishings, fixtures, equipment, and other contents. Time-consuming processes in government aid, new regulations, insurance claims adjustment, structural engineering decision-making, and building permitting contribute to long delays in the final accounting of loss data.
6. *Permanently and publicly archive disaster data.* The authors recommend coordinating loss determination via a data storage and retrieval clearinghouse. The California Governor's Office of Emergency Services served the role of storage facility after the Northridge Earthquake, but has not yet created an effective clearinghouse.

Some additional observations can be made on areas for improvement in such a study, and efforts that

EERI could undertake to improve these sources of survey data.

7. *Create mechanisms for data-checking and followup data-gathering.* It may be that government attorneys are over-cautious in their restrictions on disseminating location information. EERI could work with government agencies to review these restrictions, and perhaps find the means to protect proprietary or private information, while still making important data readily available to researchers.
8. *The accuracy of rough repair-cost estimates is unknown.* It will likely remain problematic to get repair-cost information that is both accurate and exhaustive for large populations of damaged buildings. However, it seems practical to collect accurate repair costs for a statistically significant sample set of damaged buildings, which could be compared with preliminary rough estimates. This would require access to true site addresses in preliminary assessments.
9. *More-detailed structure categories are needed.* The categories of structure type recognized by tax assessors are of limited usefulness for improving loss-estimation models. EERI could work with governments to establish more-detailed, standard structure categorization by government agencies, and establish methodologies to ensure accurate assessment of structure types.
10. *Prepare and maintain hardware, databases, and data-collection procedures.* A complete data-collection system could be constantly maintained by state or federal agencies, ready for rapid deployment in the event of a disaster.
11. *Plan for data aggregation before the earthquake.* A variety of data sources were compiled into the EQE/OES effort at great effort. These sources could be coordinated in advance to ensure a common ontology. For example, EERI could promote to state and county agencies the use of standard data elements in assessor files for earthquake-information purposes.

COORDINATING PUBLIC AND NGO DATA-COLLECTION

An effort is currently underway in California to coordinate post-earthquake damage assessments by the **Inter-Agency Damage Inspection and Assessment Working Group (2002a)**. The group comprises governmental and nongovernmental organizations (NGOs) such as the American Red Cross, local governments, the California Governor's Office of Emergency Services, the Federal Emergency Management Agency, the California Earthquake Authority, and the Small Business Administration. The participating organizations have found that after a disaster, multiple agencies contact the same people, gathering much of the same information and annoying the contacts. The group formed with the object of "reducing duplication, minimizing discrepancies, sharing common information, and implementing effective technologies." The group is not attempting to review which data are needed and why, but rather is focusing on improving the efficiency of data-gathering for currently used forms. As of this writing, the group is in the process of establishing its objectives and workplan. Objectives elucidated so far are as follows:

- Establish a forum of entities involved in damage inspection and assessment
- Compile and compare damage inspection and assessment forms and processes
- List data elements for use in identifying common information
- Evaluate technology for data-gathering and recommend hardware devices to be used
- Propose data repositories and information-sharing procedures
- Implement and field-test standardized data-gathering processes

The group has begun this effort by creating a list of 18 standard forms used by member agencies. It then cross-tabulated all the data fields (there are 544 in the current list) against the various forms on which they appear, to determine cases of duplicate questioning. Copies of the group's working documents (Inter-Agency Damage Inspection and Assessment Working Group 2002a-f) are provided in the electronic appendix. Although the group's agenda covers a variety of disasters, most of the forms are relevant to earthquakes. Earthquake-related forms tend to focus on safety (both ATC-20 forms appear in the group's list), habitability, and requests for government assistance. Little structural engineering or geotechnical data appear in them. Furthermore, it appears likely that privacy considerations will limit the dissemination of any raw data gathered using these techniques.

DATA STORAGE AND DISSEMINATION

A number of entities already discussed provide public access to earthquake-related data. TriNet, COSMOS, ROSRINE, the U.S. Geological Survey and others offer web- and ftp sites of their maps and other data. A few other resources are worth mentioning, along with an idea for a centralized archive of earthquake experience data.

GEOGRAPHIC INFORMATION SYSTEMS

California Geographic Information Systems (2001) maintains the California Spatial Information Library. This library offers a variety of GIS data, 10-meter satellite imagery, raster graphics of USGS topographic quadrangles, and interactive web-based mapping capability. The GIS data include administrative and political entities, water districts, infrastructure, cultural geography, and physical geography. Most relevant for post-earthquake investigations are the infrastructure data (airports, roads, railroads, health facilities, colleges and universities, and prisons) and the 1990 Census data. Census data show census tracts, population, racial demographics, population and housing density, and poverty statistics. The infrastructure data are limited, offering summary characteristics but no engineering features. The library does not currently offer geotechnical data.

California GIS Council (2002) and Federal Geographic Data Committee (FGDC 2002a) are working to develop standards for the compilation and depiction of spatial data in the United States. The FGDC has created a clearinghouse (**Federal Geographic Data Committee 2002b**) through which "governmental, non-profit, and commercial participants worldwide can make their collections of spatial information searchable and accessible on the Internet using free reference implementation software developed by the FGDC." Relevant clearinghouse participants include FEMA and the U.S. Geological Survey. The **Bay Area Automated Mapping Association (2002)** provides pointers to sources of GIS data for the San Francisco, California Bay Area. Some of the most relevant of these resources are discussed elsewhere in the present study.

MEDIA AND DATA FORMATS

Some brief note should be made of the electronic media and data formats available for compiling earthquake experience information. The reason is that media and format are relevant to broad and long-term data accessibility. Seismograms have historically been recorded on photographic film, heat-sensitive paper, computer punch cards, and magnetic-tape media. Sources examined here have compiled their electronic data in a variety of idiosyncratic formats and file types, for example, versions of Filemaker, SPSS, and Microsoft's Word, Excel, and Access. Both the media and the file formats over

decades become obsolete and difficult to use.

Open-Standard Formats. Regarding the physical storage of data, suffice it to say that as long as the media do not degrade and networked hardware exists to read them, they can be ported to new media as needed. Regarding file types, the World Wide Web Consortium (W3C, 2003a and 2003b) has developed Hypertext Markup Language (HTML) and Extensible Markup Language (XML). XML allows one to define a new mark-up format when HTML does not suffice, and is being used increasingly for data. Both are open standards that can be read and written by a wide variety of software. Note for example that the office suites of Microsoft Corporation (2003), Corel Corporation (2001), and Sun Microsystems (2003) are designed to export and import between their native (proprietary) formats and HTML and XML. While it is difficult to predict for how long a WordPerfect, Excel, or Access file will be readable, the W3C believes that HTML and XML will remain the lingua franca of electronic publishing for a long time by a wide variety of software.

EARTHQUAKE DATA CLEARINGHOUSE

Many data sources discussed here publicly provide online information about seismic hazard, ground motion, geotechnical conditions, and infrastructure. The FGDC clearinghouse provides assistance in disseminating any type of digital geospatial data.

Scawthorn (2001) points out that public and private entities spend significant resources in post-earthquake reconnaissance, gathering data on observed performance of the earth, earthen structures, buildings, structures, infrastructure, people, organizations, communities and economies in real earthquakes. Despite these efforts, the data tend to perish within a few years, owing to the lack of a long-term data archive. This prevents other researchers from accessing the data, merging them into larger datasets, or using them for comparative purposes. Scawthorn therefore advocates the creation of a National Earthquake Experience Database (NEED), a real or virtual data center for archiving and disseminating earthquake experience data.

NEED could conceivably employ the anticipated storage power of the George E. Brown Network for Earthquake Engineering Simulation (NEES). Scawthorn calls for the development of a design specification and implementation plan with representation by a variety of relevant research organizations such as the NEES Consortium, Earthquake Engineering Research Institute (EERI), Consortium of Universities for Research in Earthquake Engineering (CUREE), the Pacific Earthquake Engineering Research (PEER) Center, Mid-America Earthquake (MAE) Center, Multidisciplinary Center for Earthquake Engineering Research (MCEER), Applied Technology Council (ATC), the American Society of Civil Engineering's Technical Council on Lifeline Earthquake Engineering (ASCE TCLEE). The specification and implementation plan would be developed by representatives in an advisory panel and at an invitational workshop.

Some online archives already exist to disseminate earthquake experience information. The National Information Service for Earthquake Engineering (NISEE 2002) maintains the **Earthquake Image Information System (EQIIS)**. As of this writing, EQIIS contains approximately 12,500 digital images, most of which are publicly accessible, from at least 267 earthquakes between 464 BC (Sparta, Greece) to 1999 (Chi-Chi, Taiwan). Images are searchable by earthquake, structure name, subject keyword, and photographer. Open-archive procedures were successfully used for some contributions, most notably in the case of Chi-Chi. James (2002) believes that it will become increasingly important to referee contributions as the archive grows.

NISEE also maintains the **National Clearinghouse for Loma Prieta Earthquake Information (NISEE, 1991)**, established under the sponsorship of the US Geological Survey and the National Science Foundation. This archive offers 15 downloadable files and 10 additional datasets on eight CD-ROMs containing information gathered by various earth scientists, engineers, and social scientists. The breadth of topics covered is large. A number of contributions present seismicity information—before and after the earthquake—along with ground motion recordings and response spectra, geological topography, wave velocities, and permanent ground displacements. There are studies of local geology and site amplification in the San Francisco Marina District, along with experimental soil-test results of a device that measures pore water pressure, an important parameter for liquefaction. There are structural analysis input files for three instrumented buildings, and survey reports of losses to publicly-owned infrastructure. Lund and Schiff's (1991) pipeline damage database, already mentioned, is archived here. Authors provide data files for statistical analysis of risk perceptions and their impact on the housing market, of public warnings during the disaster, and of other human reactions to and casualties arising from the earthquake.

The Loma Prieta Earthquake database has a basic Web interface, with holdings described on a single page with a brief subject heading and author names. Each item has a link to an abstract. The page lacks a search tool, but it is small enough not to need one. Some items have minimal documentation, which may become a problem as the holdings and their authors age. Because the database is intended to reflect only the Loma Prieta earthquake, no means are provided for visitors to contribute additional materials regarding later earthquakes. Nonetheless, NISEE's Loma Prieta and EQIIS databases represent pioneering examples of earthquake data archives, and could provide important lessons and material contributions to an open archive for future earthquake experience data.

USING SURVEY DATA AFTER EARTHQUAKES

The foregoing text primarily deals with how earthquake-survey data are collected and analyzed by the investigators who collected them. An interesting test of the robustness of survey data is how readily they can be adapted to novel uses not envisioned when the survey was created. Several studies provide insight into robust data; four are discussed here.

ANAGNOS ET AL. (1995)

These authors set out to improve the judgmentally-derived motion-damage relationships of ATC-13 (Applied Technology Council 1985) using, not raw data, but information from available literature. They collected and analyzed empirical damage data from twelve recent publications covering California earthquakes as early as 1906. Their demands were fairly simple. They needed four pieces of information, namely: (1) by structure type and (2) shaking severity, (3) the value of property available to be damaged (its replacement cost), and (4) the cost of the actual damage. This is the minimum dataset required to evaluate a mean seismic vulnerability function.

To their dismay, the authors find that “many of these data are not particularly useful because they were collected under different formats and with different interpretations by the individuals gathering the data. In addition, ground motions are not available for the majority of the data (p. v).”

The basic problem is that the authors of the data sources were trying to solve different problems than were Anagnos et al. (1995). The former did not need all four of these data elements, and so did not collect them. This was the case with several sources that variously lacked ground-motion severity, structure type, repair cost, or replacement cost. Alternatively, the original authors extracted and published only summary information that was sufficient for immediate purposes but insufficient for other, later uses. For example,

sources fail to distinguish between repair costs and structural upgrade. The consequences that the source authors cared about varied slightly, which resulted for example in inconsistent indicators of damage: ATC-13 damage state; insurance loss in excess of deductible; Wailes and Horner damage state; or cost of reconstruction. Finally, in some cases the electronic database or even the original paper-based data had been lost. In cases where the basic paper records survived, Anagnos et al. (1995) find that the effort to extract the needed data would have been too burdensome for their means.

It should be noted that, had Anagnos et al. (1995) successfully compiled and presented all the data relevant to their purposes, their own data would have been insufficient for use in later studies with a slightly different agenda, e.g., a different structure categorization system, different measures of shaking severity, or different damage scale. Several lessons can be drawn from Anagnos et al. (1995):

1. *Use standard, well-defined terms.* This study reinforces McClure in US Coast and Geodetic Survey (1969), in that many terms commonly used to describe structure type, value, and loss can be ambiguously defined. For example, repair cost is different from insurance claim amount and from the cost of work shown on a building permit. An unambiguous, standard set of definitions (an *ontology*, in information-technology argot) is crucial to communicating about earthquake consequences. Such an ontology could be established, maintained, and disseminated by professional societies or governmental institutions, similar to standards established by the American Society for Testing and Materials (ASTM).
2. *Use multiple or universal terminology.* Inconsistent terminology for describing location, ground motion, structure type, and loss can thwart researchers' attempts to synthesize disparate datasets. This problem could be addressed by gathering and storing data at a level of detail in excess of the researcher's immediate needs. Repair cost, for example, could be recorded in terms of dollars or perhaps dollars for each of several repair tasks, as opposed to ranges of damage factors.
3. *Permanently store data in electronic format.* While paper records are available in some cases, they can be too burdensome for use in studies that involve large numbers of facilities. It would be help if inexpensive means were available to transcribe or scan paper data to electronic format and, just as importantly, to store these data in a curated archive. This is true regardless of access rights, considering the many cases in which original data-gatherers lose their underlying paper or electronic files.
4. *Allow for cross-referencing of location.* Seismic excitation can vary substantially within a ZIP Code. Location references could include latitude and longitude, or street address range number, without compromising privacy.

COMERIO ET AL. (1996)

This study for the California Policy Seminar examines disaster-response and recovery programs. The study emphasizes changes to government-assistance programs, earthquake insurance, and their effectiveness in benefiting populations in need. The authors examine the history and interrelated roles of the major government and nongovernmental organizations (NGOs) in disaster response and recovery. They provide chronologies of government and NGO activities following several key California disasters since 1989, and examine in depth the residential losses that resulted from the 1994 Northridge Earthquake, with special attention to the implications and limitations of the database compiled by the California Governor's Office of Emergency Services. They discuss modeling issues and their relevance for future earthquakes. These last two topics—the damage database and loss

modeling—are particularly relevant to the present study.

Regarding modeling issues, the authors find poor results from their regression analyses that relate aggregate inspector-estimated losses to dwelling size, safety-inspection tag color, shaking severity (peak ground acceleration), and a few other parameters. The authors observe that linear regression against these independent variables account for no more than 20 to 40% of the variance of ZIP-Code-aggregate losses. They attribute these poor results to the general shortcomings of loss models that work on an aggregate basis. They conclude that building-specific exposure information is crucial to developing accurate predictive models of loss, including detailed building design, condition, and seismic rehabilitation, and site soils.

The authors comment on how the quality and level of detail in inspection data vary by jurisdiction and inspector. Inspectors estimated repair costs in some jurisdictions but not others. Some recorded number of habitable and uninhabitable units in multi-family dwellings, while others did not. As already noted, a generalized structure type was available for buildings in Los Angeles County but not in Ventura County. The authors also comment upon the completeness of the EQE/OES database, comparing it with ZIP-Code aggregate claims data collected from insurers by the California Department of Insurance, and concluding that the public-inspection database “drastically underestimates the dollar value of damage to both single and multifamily structures.”

Some of these problems have been mitigated since 1994. Future government efforts to compile wide-scale loss data most likely will continue to rely on ATC-20 safety-evaluation forms, current versions of which require the inspector to note structure type, inhabitable and uninhabitable dwellings, and range of building damage factor. However, the newer ATC-20 forms probably will not materially improve the accuracy or completeness of repair-cost estimates, since they rely on the same rapid visual assessments—often based on limited exterior inspection—that characterized inspections by building officials in the Northridge Earthquake.

Furthermore, these inspections are performed primarily for buildings whose safety is questionable, rather than on a population basis or for statistically unbiased samples. The authors also determine, via comparison of the OES database with insurance data, that many homeowners call their insurance agent or lender to perform post-earthquake inspections rather than the building department. The implication is that loss models that depend solely on building-department inspection data for seismic vulnerability data are prone to underestimate actual damage.

While extrapolation from a statistically biased sample set to the population is conceptually possible, it is a daunting challenge. However, given that the focus of future efforts will likely be similar to that undertaken by OES after the Northridge Earthquake, it would probably be valuable for EERI to encourage research to provide a sound basis for such extrapolation.

CUREE-CALTECH WOODFRAME PROJECT (PORTER ET AL. 2002)

This project by the present author and colleagues set out to model the seismic vulnerability of 19 particular woodframe dwellings on a building-specific basis. Earlier studies have attempted similar ends, but this one is examined here both because of its familiarity to the present author, and because it models building performance in greater detail than do earlier efforts. Our objective was to assess the benefits of seismic retrofit or redesign measures and the effect of construction quality on future seismic performance. The methodology for this project, entitled assembly-based vulnerability (ABV), models building-specific seismic vulnerability using an engineering model of the building and its components. One aggregates the

modeled behavior of the components to characterize the performance of the entire building. This is in contrast with whole-building approaches that employ empirical data or judgment about overall losses to entire buildings. Like a whole-building approach in miniature, ABV creates its component performance models using four pieces of information: (1) by highly detailed component type and (2) level of structural response (such as interstory drift or floor acceleration), one must know (3) the quantity of similar components exposed to damage and (4) the quantity of components so damaged.

This effort focuses on woodframe construction, and so requires performance information about woodframed gypsum wallboard partitions, stucco exterior walls, woodframed walls with plywood and oriented strandboard (OSB) structural sheathing, windows of various sizes, and residential water heaters. Because the study sought to distinguish the effects of important details, it discriminates between components at a highly detailed level, essentially equivalent to the level of detail that laboratory tests examine. Our component taxonomy is that of R.S. Means Co., Inc.'s (2000) assembly-numbering system, enhanced to indicate details of seismic resistance. The use of this standard helps in estimating repair costs, and is particularly useful because it is so well established. With its modest enhancements, this system provides the necessary level of detail.

Interestingly, despite the effectively boundless source of performance information about how these components performed in recent earthquakes, we found that actual field data available in the literature are inadequate to describe the performance of these components in the needed terms. In the end, it was necessary to use a limited quantity of laboratory tests to characterize component performance, which could not be directly compared with real-world earthquake experience. Three general shortcomings of real-world performance data caused this. First, the data lack the structural response to which components were subjected. Second, the field data do not record engineering details such as nail spacing, stucco strength, window dimensions, and other features that laboratory tests, by contrast, explicitly examine. Third, damage questionnaires are ambiguous about whether the surveyor is supposed to be recording fragility or vulnerability information. (Fragility involves the fraction of components of a particular type that had suffered damage of a particular nature, whereas vulnerability addresses loss, often as a fraction of replacement cost.) The lessons one can draw from this study therefore echo those of researchers who attempt to model whole-building losses:

1. *Define and measure components using a standard and detailed taxonomic system.* R.S. Means Co., Inc.'s (2000) assembly-numbering system is a good starting point. While the level of detail might seem burdensome, it avoids the over-aggregation that proves so common in other studies. The detail can always be aggregated out after the fact, while the reverse is not true: one cannot add detail to overly-aggregated performance data.
2. *Distinguish between fragility and vulnerability.* To create fragility functions requires information about the fraction of components damaged as a function of seismic excitation, whereas vulnerability functions require information about loss (often as a fraction of exposed value) as a function of seismic excitation. Future efforts should be clear about how damage is to be measured. Fragility information is readily gathered in initial surveys, before repairs are undertaken and their costs are known. Follow-up surveys can undertake to collect loss data.
3. *Prepare in advance to measure seismic excitation of important components.* To learn about the performance of portions of structures requires that one know the excitation to which that component was subjected, the interstory drift index of a wall segment, for example. Excitation can often be inferred from shaking severity and basic structure information, but not with the accuracy commonly demanded of laboratory tests. EERI should support efforts to install strong-motion

instruments in significant numbers of facilities that include important component types.

CONCLUSIONS AND RECOMMENDATIONS

A rich literature of data-gathering protocols exists to gather information about earth-science, engineering, and social-science aspects of earthquake experience. From these studies we can draw several generalizations.

Protocols exist to collect data on most aspects of earthquake experience. Research reviewed here provides formal means to quantify: ground motion; site soils; characteristics of existing buildings and bridges; physical damage to buildings, contents, equipment, and lifelines; deaths and injuries; human behavior; business disruption; and other economic impacts. Authors have studied how best to integrate data from multiple sources so as to understand an earthquake's macroscopic socioeconomic effects.

Protocols vary between researchers and over time. Limited consistency exists between protocols developed by different researchers, and it can be difficult to compare or aggregate these studies. No entity standardizes earthquake-data protocols, so they tend primarily to serve the immediate needs and interests of the researchers who design them. Furthermore, protocols carried out by a single research group evolve over time, both as survey problems are corrected, and as additional issues are addressed.

Raw data perish. Raw data are typically unavailable, either because they are too voluminous to publish, or for the privacy of individual facilities and respondents. No single entity exists to serve as a clearinghouse of earthquake experience data. As a consequence, raw data tend to perish, and it becomes difficult to compile data from different researchers and different earthquakes, which hinders long-term research. Important, pioneering efforts have been undertaken to store and disseminate data collected by others, but with limited exceptions, these efforts focus primarily on seismological issues.

The present research has highlighted many procedural and technological opportunities to overcome these limitations.

1. *Provide consistency and clear directions.* Several authors find that to compile a meaningful dataset requires that the data gatherers or survey respondents possess clear definitions and procedural guidelines before they begin. Researchers should test and refine data-gathering instruments. Where possible, use multiple-choice questions and anticipate problems that might lead to no answer.
2. *Consider comprehensibility to outside readers.* Several authors call for clearly defining all terms in final publications. One should not assume that all interested readers possess familiarity with specialized terminology. Where possible, use well-established, standardized definitions and categorization systems. Professional societies can assist by developing and disseminating these through permanent committees and websites.
3. *Demonstrate scientific basis for conclusions.* It is common to provide summary results but not to demonstrate that data-gathering instruments or raw data are available for review and verification purposes. Brief research summaries are valuable for communicating the important conclusions of a study, but rigorous defense of those conclusions requires that others can check them. EERI could encourage publication of raw data and data-gathering instruments by insisting that assertions made in its publications be supportable from published raw data and data-gathering procedures, even if these data and procedures are documented elsewhere.
4. *Provide for aggregating data with earlier or later efforts.* Publishing raw data and survey instruments can

also benefit later efforts, by allowing subsequent researchers to compile earthquake lessons from various times and places. Toward this end, it may also help to use terms and definitions consistent with earlier efforts.

5. *Avoid loss of data through obsolete formats.* It is valuable for electronic data to be presented in multiple file formats and media, with an eye to formats and media most likely to be supported for decades. When creating an electronic database, include copies in nonproprietary formats such XML or comma-and-quote-delimited ASCII text. Include durable electronic media with paper text. Avoid compression formats that are likely to become obsolete or are unique to an operating system.
6. *Minimize duplication of data-gathering efforts.* Develop and disseminate standard electronic forms and databases that can be used by others, if it is reasonably anticipated that other entities will find them useful.
7. *Provide for statistical analysis.* Without statistical data, earthquake reconnaissance primarily provides anecdotal insight into possible failure modes, achievable capacities, and common behaviors. As interesting as these are, scientific advancement often requires large, unbiased datasets with the possibility of statistical analysis to test hypotheses.
8. *Avoid over-aggregation.* Where practical, provide a level of detail beyond that needed for present purposes. Others may find it useful in the future.
9. *Provide incentives.* Respondents may cooperate more readily with surveyors if they are offered incentives to participate, are assured of the importance of their replies, and are thanked for their efforts.
10. *Promote dense instrumentation.* Motion-damage relationships cannot be greatly improved by earthquake experience if seismic excitation, in site-specific, instrumental terms, is unknown. This includes both ground-motion excitation and structural response. Few low-rise and mid-rise buildings are instrumented to capture responses of interest such as interstory drift ratios and upper-story floor accelerations.
11. *Use predictive tools for data-gathering.* Tools such as ATC-21, ATC-50, and the Johnson et al. (1999) forms can provide useful taxonomic systems, training tools, and clear, well-tested multiple-choice forms for describing facility features. Their extensive sample datasets can also represent large experiments waiting to be performed.
12. *Domicile reports and data at permanent, curated archives.* Archive paper documents at numerous libraries, in acknowledgement of the fact that a single-source publisher may not exist or may lose original manuscripts or data files within a few years or decades. Anticipate that electronic media may become obsolete and unreadable. Publish redundant data online through durable institutions. A truly long-term solution to publishing raw data may require the creation of an institution that provides electronic, curated open archives where researchers can deposit their data and discover data compiled by others.

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ABBREVIATIONS

ABV, Assembly-Based Vulnerability
ANSS, Advanced National Seismic System
ASCE, American Society of Civil Engineering
ASCII, American Standard Code for Information Interchange
ASTM, American Society for Testing and Materials
ATC, Applied Technology Council
CIIM, Community Internet Intensity Maps
CISN, California Integrated Seismic Network
COSMOS, Consortium of Organizations for Strong-Motion Observation Systems
CSMIP, California Strong-Motion Instrumentation Program
CUBE, Caltech US Geological Survey Broadcast of Earthquakes
CUREE, Consortium of Universities for Research in Earthquake Engineering
DMS, Development Management System
EERI, Earthquake Engineering Research Institute
EPRI, Electric Power Research Institute
EQIIS, Earthquake Image Information System
ERS, Emergency Response System
FEMA, Federal Emergency Management Agency
FGDC, Federal Geographic Data Committee
FHA, Federal Housing Administration
GIS, Geographic Information System
HAZUS, Hazards United States
JMA, Japan Meteorological Agency
MAE, Mid-America Earthquake Center
MCEER, Multidisciplinary Center for Earthquake Engineering Research
MMI, Modified Mercalli Intensity
MPS, Minimum Property Standards
NEED, National Earthquake Experience Database
NEES, Network for Earthquake Engineering Simulation
NEHRP, National Earthquake Hazards Reduction Program
NGO, Nongovernmental organization
NIBS, National Institute of Building Sciences
NISEE, National Information Service for Earthquake Engineering
OES, Office of Emergency Services
OSB, Oriented strandboard
PCS, Property Claim Services
PEER, Pacific Earthquake Engineering Research Center
PGA, Peak ground acceleration
PMF, Performance modification factor
ROSRINE, Resolution of Site Response Issues from the Northridge Earthquake
SAC, Structural Engineers Association of California, Applied Technology Council, and the Consortium of Universities for Research in Earthquake Engineering (a joint venture of these three entities)

SEAOC, Structural Engineers Association of California
SMS, Structural Maintenance Systems
TCLEE, Technical Council on Lifeline Earthquake Engineering
TCP/IP, Transmission Control Protocol and Internet Protocol
UBC, Uniform Building Code
USGS, United States Geological Survey
W3C, World Wide Web Consortium
WSMF, welded-steel moment frame
XML, Extensible Markup Language

ELECTRONIC APPENDIX

Universal resource locators (URLs) are provided for many of the references cited here. Furthermore, this document and an electronic appendix are available on CD-ROM from EERI, in several formats. The present study is provided in Microsoft Word 2002, HTML, and Adobe Acrobat formats. The electronic appendix is provided in Adobe Acrobat and JPEG formats. It contains the following materials:

1. Applied Technology Council (1988) ATC-21 Screening Forms and NEHRP Map
2. Applied Technology Council (1992) ATC-31 Revised Survey Form
3. Applied Technology Council (1996) ATC-20 forms and placards
4. Applied Technology Council (2000) ATC-38 Postearthquake Building Performance Assessment Form
5. Applied Technology Council (2002a) ATC-21 (FEMA-154) Data Collection Forms
6. Applied Technology Council (2002b, draft) ATC-50 Simplified Seismic Assessment Form
7. Basoz and Kiremidjian (1996) Bridge Taxonomy
8. Bourque et al. (1994) Loma Prieta Survey Codebook
9. Byerly and Dyk (1936) Form 680
10. Committee on Assessing the Costs of Natural Disasters (1999) Direct Losses Table
11. Durkin (1995) Prevalence Survey Form
12. Earthquake Engineering Research Institute (2000) Post-Earthquake Investigations Field Guide forms
13. Inter-Agency Damage Inspection and Assessment Working Group (IADIAWG, 2002) PDA documents
14. McClure (1973) San Fernando Earthquake Dwelling Damage Survey Form
15. NIBS and FEMA (1999) extracts from HAZUS 99 Technical Manual
16. Rutherford & Chekene (1990) City of San Francisco UMB Supplementary Damage Collection Form
17. SAC Joint Venture (2000) FEMA 352 Appendix C Sample Inspection Forms
18. Saeki et al. (2000) Classification of Household Property
19. Tierney (1997) Des Moines Business Study questionnaire
20. Tierney (1997) Los Angeles Business Study questionnaire
21. U.S. Geological Survey (2001) Community Internet Intensity Map (CIIM) sample questionnaire



APPENDIX E

AN OVERVIEW OF POST-EARTHQUAKE DAMAGE ASSESSMENT IN ITALY

BY A. GORETTI AND G. DI PASQUALE

EERI INVITATIONAL WORKSHOP
AN ACTION PLAN TO DEVELOP EARTHQUAKE DAMAGE AND LOSS DATA PROTOCOLS
September 19th and 20th, 2002 , Pasadena, California

AN OVERVIEW OF POST-EARTHQUAKE DAMAGE ASSESSMENT IN ITALY

A. Goretti, G. Di Pasquale
(National Seismic Survey, Department of Civil Protection, Italy)

SUMMARY

For many years in Italy post-earthquake damage assessment has been one of the preliminary steps for the establishment of a proper reconstruction strategy. Although the main purpose of the damage assessment has always been to estimate direct economic loss, 1st level damage data and building type data have also been collected extensively after both destructive and non-destructive earthquakes. This has enabled the performance of statistical analyses using damage data and building type, obtaining correlations with seismic intensity, if the latter is known. This paper describes historic and recent Italian experiences in the field of damage assessment, highlighting past problems, as well as issues that have not yet been resolved in assessing procedures, forms, tools, computerisation, validation, maintenance, and data dissemination.

INTRODUCTION

In Italy post-earthquake damage assessment has been performed for many centuries. After the 1570-1574 Ferrara Earthquake (IX MCS), the duke Estensi gave the architect Ligorio, who belonged to the papal court, the responsibility for damage evaluation. His report addressed both public and private buildings and was so detailed that it has been possible to locate the most damaged buildings on a plan of the town. The report describes also many of the local building techniques and includes a surprising list of vulnerability factors, including the “a sacco” masonry walls, thrusting roofs, and offset floors. At that time no economic contribution was made by the Duke for the building reconstruction. The Pope reduced to 75% the taxes in order to facilitate the repair of the damaged churches (Guidoboni, 1987).

In the XVII-XX century in central Italy, damage surveys mainly addressed financial contributions. In the Tuscany Grand Duchy, after the 1661 earthquake, the Grand Duke (Medici) required inspections in the stricken localities and an engineer was in charge of the damage assessment of the fortress. After the same earthquake the Papal State made an estimate of the overall economic loss in Romagna. The same happened after the 1688 earthquake when results of an expert’s report were communicated to the cardinal. After the 1781 earthquake the city of Faenza evaluated the economic loss, asking Rome for contribution. The post-earthquake reconstruction was made easier with loans, tax reductions and financial contribution for the poor (Guidoboni, 1987).

After the unification of Italy, the Kingdom faced the 1887 Liguria earthquake ($M=6.0$, $I_0=IX^1$), the first seismic emergency of the new State, and the two catastrophic events of Messina, 1908 ($M=7.2$, $I_0=XI$) and Fucino, 1915 ($M=7.0$, $I_0=XI$). On those occasions, the damage surveys were performed through experts’ reports made by the State (Civil) Engineers (National Seismic Survey, 2001).

After the II World War the Italian Republic faced the Belice 1968 ($M=6.1$, $I_0=X$), Friuli 1976 ($M=6.4$, $I_0=IX-X$), Irpinia 1980 ($M=6.9$, $I_0=IX-X$) and Umbria-Marche ’97 ($M=5.8$, $I_0=IX-X$) destructive earthquakes. Non destructive earthquakes, such as the Parma 1983 ($M=4.8$, $I_0=VI-VII$), Abruzzo 1984 ($M=5.6$, $I_0=VIII$) and Pollino 1998 ($M=5.5$, $I_0=VI-VII$) earthquakes, have also been very important in assessing methodologies, procedures and protocols, (National Seismic Survey, 2001). During the last thirty years or so, a process of decentralisation has occurred and the damage survey has changed from a State to a Regional or Municipal duty, as after the Parma 1983 earthquake. This decentralisation, together with the lack of a unifying trend, has been the reason why each earthquake has been managed differently, in terms of procedures, forms, inspectors, etc. The Umbria-Marche earthquake, the first time when the damage survey has been performed together with the usability survey, has been the beginning of an overall revision. Very recently, a standardised procedure for usability and damage assessment has been proposed by the Italian National Civil Protection and the National Seismic Survey (SSN) for all the Italian Regions and a training programme has started.

¹ Data of Magnitude M and epicentral intensity I_0 in MCS scale, up to 1992, are from (ING-GNDT-SGA-SSN, 1999). Magnitude M is obtained as weighted mean of macroseismic and instrumental values.

CLASSIFICATION OF DAMAGE COLLECTION

The classification of damage collection can be done in different ways, depending on the aim of the survey, including by discipline, by time when data are collected, by the accuracy of the data (I, II or III level data²), by the amount of data to be collected, by the perishable nature of the data. Many of the above items are strictly correlated and in the following three possible classifications will be presented, based on the aim of the data collection, the involved discipline and the time when data are collected. The latter criterion is more rational for establishing a proper strategy for data collection and it is very similar to a recent Japanese classification (Building Research Institute, 2002).

Classification by purpose (“Why”):

- Short term usability assessment;
- Assessment of the overall economic loss or of the overall funding needed for reconstruction;
- Evaluation of the individual contributions;
- Social impact assessment;
- Prevention and emergency management;
- Scientific purposes.

Classification by discipline:

- Geosciences: primarily concerned with strong ground motion data collection. Soil is permanently monitored by means of the Italian accelerogram network and data are collected at National Seismic Survey and are available on Internet. Mobile network is installed by SSN and by other institutions (as Universities or National Institute for Geophysics) after the event. In case of other institutions, they define the access to collected data.
- Structural Engineering, buildings: few buildings are permanently monitored by SSN and the recorded data are available when the event triggers the instruments. Extensive damage collection is performed after the event for reconstruction purposes. In this case buildings are temporarily monitored and there is high risk that some data perish. A similar extensive damage collection is performed on churches.
- Structural Engineering, other built systems: due to the moderate intensities of Italian earthquakes, damage to lifelines or transportation systems is usually very limited. Data are not collected in a systematic way.
- Social sciences: homeless are recorded for each inspected building, while injured and fatalities are collected as aggregate data. Up to now no other data are systematically collected after the event.
- Economy (overall impact of the earthquake): no data are systematically collected after the event, mostly due to the long period of time and to the large geographical area that has to be monitored in order to collect significant data. Obviously records of the funding for reconstruction are available.

The above classification gives an idea of what kind of data are available, but do not give insight into the data collection process, that is “when”, “how many”, “what accuracy”. A different possible classification scheme is thus presented, based on when data are collected. What will be presented for buildings can be easily applied to a different discipline.

Classification by “When” data are collected:

- Pre-event: The inventory for risk analysis or damage/emergency scenario is usually built up with I-level accuracy. The survey is not directly related to damage collection, but sometimes the pre-event database can provide the “denominator” if post-earthquake damage collection is performed only on the damaged buildings. Detailed III-level data are collected on permanently monitored buildings. They could be also collected on pre-selected buildings, when showing a seismic behaviour reputed to be investigated.
- Post-event 2-3 days, 2-3 weeks: this is the time of the preliminary macroseismic intensity assessment (2-3 days) and of the reconnaissance survey (2-3 weeks). Data are not systematically collected. The Authors believe it is possible to collect some aggregate data in a fuzzy way, being useful in the immediate updating of the damage scenario.
- Post-event 3-60 days: During this period, the usability and damage assessment is performed. I-level data are collected on a large number of buildings. As the inspections are performed at the request of citizens, the collected data are generally biased.
- Post-event 30 days-some years. In order to get unbiased data from the usability and damage assessment, a comprehensive survey is conducted, with I-level accuracy, in selected localities. III-level accuracy data are collected on the permanently monitored buildings or on buildings with peculiar seismic behaviour.

The above classification shows that a high accuracy of the collected data (III-level data) is not consistent with a huge number of inspected buildings. It could be interesting to check if the number of inspected buildings times the number of data per building is somehow constant when data are collected with different levels of accuracy (I, II or III level data). Moreover, similar to other countries (Japan, Turkey), it appears that if damage statistics are to be

² Level I data are limited to information that can be collected through a simple and quick visual inspection, level II data include additional elements on the structural characteristics, level III are data needed for an engineering evaluation.

collected on a huge number of buildings, the process should be performed under an “official” umbrella and possibly with a well-identified social value.

PRE-EVENT DAMAGE COLLECTION

In recent years a systematic typological, dimensional and functional data collection for residential and public built systems has been carried out in Southern Italy. The surveys have been funded by the National Civil Protection, as part of a seismic prediction program, and by the Ministry of Labor, as social workers were used in the survey.

In the years 1996-97 all public buildings (more than 40,000) in 1748 Municipalities in Southern Italy have been surveyed with a I and II level form by about 600 technicians (GNDT et al, 1999).

In 1996-1998 a sample of the private buildings was surveyed in the same Region (25,000 buildings, 1032 surveyors and tutors). The sample has been selected on the basis of information derived from Census³ (GNDT et al, 2000).

In 1998–2000, the monumental buildings (1900 among churches and other buildings) located in different parks in Southern Italy and all the buildings located in 200 municipalities have been surveyed. In the latter case a quick inspection form, less detailed than the usual I level form, was used (GNDT et al., 2001).

In the same years a survey of lifelines was performed (water, sewage, electricity, gas, roads and railways). When data were not accessible with visual inspection, data were obtained by means of design drawings or interviews with local technicians.

In the Catania Project (Faccioli and Pessina, 2000), funded by GNDT, 12,500 residential masonry buildings, 6,500 residential RC buildings and 700 public buildings were surveyed with a quick inspection form.

Most of the data have been validated and computerised. Data related to lifelines have been only partially validated and computerised.

Due to a sudden collapse of few residential buildings, a recently proposed, but never approved, national law promotes the realisation, for every building in the whole country, of a booklet containing, among other items, also rough information on typology. It can be the start of a national inventory based on more technical data, as today it can be obtained only by means of the national Census data.

POST-EVENT DAMAGE AND USABILITY ASSESSMENT

The post-earthquake usability and damage evaluation is, at present, the major source of damage collection in Italy, as it is also in Turkey and Japan. Comparing different methodologies of damage collection, an important distinction should be made between: a) usability and b) damage survey. Post-earthquake usability assessment is commonly aimed to evaluate the possible short term use of the building (Building Research Institute, 2002; ATC-20, 1989, ATC20-2, 1995; Baggio et al, 2000; Goretti 2001; Dandoulaki et al, 1998). During the assessment, the buildings that can be safely used, in case of aftershocks, are determined, together with the emergency measures to be taken in order to reduce the risk for people.

On the other hand, there are many reasons why damage surveys are performed (Building Research Institute, 2002; Baggio et al, 2000). In Japan the aim of the damage assessment is to evaluate the long term use of the buildings. The result of the evaluation is a suggestion to the owner of the building concerning the repair, the retrofit or the demolition of the building. In Italy something similar happened in the past, but today the main purpose of the damage survey is to evaluate the usability and the overall amount of direct economic loss, useful to establish the financial contribution of the government for the reconstruction. The decision on long term use of the building is postponed to an engineering evaluation in the reconstruction process. In Greece damage survey is not performed, because financial contribution are established on the basis of the usability classification. In Turkey the damage classification is used to assign the financial contribution to each buildings. In the United States, to the writer's knowledge, a systematic damage collection, in terms of suffered physical damage, is not performed by Federal or State agencies.

Strictly related to the aim of the damage survey is the way in which it is performed. In Italy not very detailed information are required and the data collection can be performed together with the usability survey. The advantage is to speed up the overall survey and hence the reconstruction process, as it is demonstrated (Kaas et al, 1987) that the time for the reconstruction process is very strictly related to the time for the emergency phase. The main drawback of this joint survey is to slow down the completion of the usability survey, although many of the data to be collected in the damage survey need to be taken into account in the usability survey. The slow-down is compensated by the fact that, in Italy, the usability and damage survey is performed in 2 steps, with a limited percentage of buildings requiring the second inspection (about 5%). In Greece and US the usability assessment is still performed in 2 steps, apart the engineering evaluation in US, but the number of buildings requiring the second inspection is very high. Main features of the usability and damage assessment in some countries all over the world are summarised in table 1 (Building Research Institute, 2002; ATC-20, 1989, ATC20-2, 1995; Baggio et al, 2000; Goretti 2001; Dandoulaki et al, 1998).

³ Every 10 years a national census on population and dwellings is carried out in Italy by ISTAT (National Institute for Statistics). During this census also raw data on dwellings are recorded (floor area, age, number of floors in the building, etc.)

Table 1. Purpose of the usability and damage survey in Italy, Greece, Turkey, USA and Japan

	Usability survey	Steps	Damage survey	Survey
Italy	Short term use of the building	2	Establish overall amount of direct economic loss	Joint
Greece	Short term use of the building	2	Not performed	
Turkey	Short term use of the building	1	Establish financial contribution for each building	Distinct
USA	Short term use of the building	3	Not performed	
Japan	Short term use of the building	1	Suggestion for long term use of buildings	Distinct

It is worthwhile to mention other important “derived products” of the damage survey in Italy. They are: a) the macroseismic intensity assessment (Galli et al., 2001, Di Pasquale & Galli, 2001), b) the vulnerability assessment (Braga et al., 1982), c) the building classification (Zuccaro et al., 2000) and d) the site effects evaluation (Goretti and Dolce, 2002). It is also necessary to point out that the post-event usability and damage assessment is very different from the same assessment performed pre-event. This is particularly relevant in case of usability assessment, but it applies also to damage collection if a huge number of buildings is involved. Main features of the post-earthquake usability and damage evaluation, together with their consequences, are reported in table 2.

Table 2. Features and consequences for the post-earthquake usability and damage assessment

Features	Consequences for usability assessment	Consequences for damage assessment
1 The seismic crisis is not ended	A new shock can occur. It must be taken into account in the usability evaluation. The assessment is valid until a new shock occurs. Reduced safety level should be accepted.	Cumulative damage is often recorded, while soil motion is recorded for each shock. A cumulative macroseismic felt intensity is usually assigned.
2 The number of inspections is very huge	Many inspectors are required, the inspection management should be effective and computerised. Procedures and forms should be prepared, and inspectors trained, before the event.	
3 Inspections should be completed as soon as possible in order to reduce the risk for inhabitants (usability assessment) and/or to speed up the reconstruction process (damage assessment).	The available time for the inspection is very limited. It is not possible to make a detailed dimensional and/or mechanical data collection and/or numerical analysis. Usability assessment must be based on visual inspection and on expert judgement, but also on interviews with local technicians to gather information on the local constructive practice.	The available time for the damage assessment is very limited. Collected data can only be I level data, mainly the observed physical damage, the building type and rough dimensional data.

All the previous items interact with each other. For instance new shocks can increase the number of inspections to be performed, requiring more inspectors. The number of inspected buildings in recent Italian earthquakes is reported in table 3, where I_0 is the epicentral intensity and some data are to be considered approximate, based on extrapolations.

Table 3. Inspected and unusable buildings in recent Italian seismic events

Event	Year	I_0 (MCS)	Inspections	Unusable buildings
Friuli	1976	X	>70,000 ([§])	43,000 (*)
Irpinia	1980	X	38-250,000 (+)	120,000 (^)
Abruzzo	1984	VI-VII	51,000	N.A.
Marche	1997	IX-X	100,000	27,000 (27%)
Pollino	1998	VI-VII	18,000	4,100 (22%)

([§]) Damage assessment

(*) Damaged or collapsed buildings

(+) Damage assessment on all the 38,000 buildings in 41 Municipalities, about 250,000 inspections on damaged buildings in all the Municipalities

(^) Estimated from 480,000 damaged or collapsed dwellings

The number of inspected buildings reported in table I can be compared with the 65,000 buildings inspected in Athens in 1999 (usability assessment) and the 46,000 buildings inspected in Kobe in 1985 (damage assessment). It should be noted that after the Kobe earthquake about 144,000 buildings collapsed or were heavily damaged. Hence the damage assessment was performed on a selected set of damaged buildings. From table I, one can see that, after destructive earthquakes, the number of buildings to be inspected can easily be in the range of 80-100,000, and could grow even more if a big city were involved.

If a large number of buildings are inspected before the event, the differences between pre-event and post-event survey are obviously reduced. In fact procedures and forms used in the pre-event survey of public and private buildings in Southern Italy were similar to the ones used in the post-earthquake damage and usability assessment.

Before analysing the present usability and damage assessment methodology, it is interesting to summarise the past experiences, starting from the 1976 Friuli earthquake. In the following the overall procedures and forms will be compared, while in the next paragraph more emphasis will be devoted to building type and damage data collection.

After the Friuli earthquake in north-eastern Italy (May 6, 1976, $M_s=6.5$, about 900 fatalities, an important second shock in September) a comprehensive damage survey was carried out by the Region with the main purpose of assessing the economic loss and gathering an initial indication whether to repair or rebuild the damaged buildings. The survey was carried out on all the real estate stock in the epicentral zone and on its damaged portion in the other zones. The form used was entitled "Minutes for the damage assessment of residential or mixed use buildings" and consisted of five sheets:

- Sheet 1) general data relevant to the building (address, reference in map, use, number of stories), damage in term of the estimate of repairability (destroyed, not repairable, repairable totally or partially, repair not needed) and estimate of the repair cost as summary of sheets 3 and 4;
- Sheet 2) general data concerning each dwelling in the building (number of rooms, number of peoples, type of occupancy, owner or manager, ...);
- Sheet 3) summary of the data used for the cost estimate (dimensions, volume, value of the building before the earthquake, repair cost) obtained collecting the data of sheets 4);
- Sheet 4) a sheet reporting the type of vertical and horizontal components, the type of finishing and plant, with the corresponding percentage of damage and the estimate of the repair cost;
- Sheet 5) Preliminary indication on the repair works.

As can be seen, the inspector was responsible for the decision of the emergency measures, of the building repairability and of the cost estimate. No detailed data were collected for the destroyed buildings because in those cases rebuilding was the only possible option. Udine University recently set up a database with the most relevant information recorded in the minutes, that were initially only on paper. The database, called FrED (Friuli Earthquake Damage Data) and containing about 76,000 damaged buildings, has now been transferred to SSN.

It is important to note that most of the damage assessments in the epicentral zone was performed after the first shock, May '76. Other parts of the territory were surveyed after the second shock, September '76, so most of the macroseismic data cumulate the effects of the two shocks.

After the Irpinia earthquake in Southern Italy November 11, 1980, ($M_s=6.9$, about 3,000 fatalities) two different inspections were carried out:

- the first one, extended to the whole building stock (38,000 damaged and undamaged buildings) in 41 Municipalities, in order to have an unbiased sample. Felt intensities ranged from V to IX-X MCS. Main aim of the survey, carried out by expert teams with the cooperation of the military technicians, was the estimate of the overall economic loss;
- the second one was extended to all the damaged buildings in all the Municipalities stricken by the earthquake (more than 600). It was carried out by professionals managed by the Regions, with a form different from the previous one.

The form used in the first survey was very concise, it contained only one page. A field manual was added, aimed to explain how to evaluate the structural typology and the damage level, being the last one recorded separately for each structural and non structural component in a discrete, 8 levels, scale. About 38,000 records are available, most of them concerning masonry buildings.

The form used for the second survey was simpler. One part was devoted to the whole building and another to each dwelling or property in the building. The damage assessment, in this case, was essentially limited to an overall judgement on repairability. The number of inspected buildings is very huge. In the small Basilicata Region about 228,000 dwellings in 72,000 buildings were inspected. Data were computerised on tapes by the Region and never updated. Today it is quite difficult to retrieve the data from these tapes.

After the Abruzzo earthquake in Central Italy (May 7 and 11, 1984, $M_s=5.8$, 3 fatalities) the damage survey managed by GNDT, was carried out in more than 240 municipalities. The aim of the survey was the usability assessment and the estimate of the repair cost. A revision of a previous form, created by GNDT for the damage assessment after the Parma 1983 earthquake, was used. The database contains about 51,000 inspected buildings, but only 15,000 can be referred to Municipalities completely surveyed. In the other municipalities the percentage of non inspected buildings is not negligible.

In 1985 a new form, specifically aimed at the quick safety evaluation, was proposed by GNDT (Gavarini, 1985). In the 1 page form, all the items to be considered in the usability assessment were listed and guidance was given to the decision pattern, through a point system combining different penalties for each surveyed item. This interesting procedure was also implemented in an expert system, but has had very few applications.

After the Umbria-Marche earthquake, Central Italy (September 26, 1997 Ms=5.9, 11 fatalities, aftershocks up to April 1998), the two involved Regions used different forms and the inspections were managed in different ways. However, in both the Regions a joint usability and damage survey was performed.

The Umbria Region had previously developed a 1 page form primarily to record the general features of the buildings (surface, stories, occupancy, maintenance before the earthquake,) the damage (five damage levels for the main components) and the data required to estimate the repair cost (length and thickness of walls, proposed intervention and their extension). The form was not too clear, required too much time to fill in each section and as a result only a few sections were filled in. An overall evaluation of the repair cost was also required by the inspectors. As no building usability classification was included in the form, inspectors were required to write their judgement on the building safety on the forms. Every building was surveyed in the urban centres of the epicentral area and on request in the non epicentral area or outside the urban centres in the epicentral area.

The Marche Region did not have any predefined procedure or form. A preliminary form, developed by SSN and GNDT, was then used. The form was specifically conceived to give guidance in the safety assessment and it was much easier to fill in than the one used in the Umbria Region. Most of the information to be collected was in a predefined format, so only a mark was necessary to record the data. About 38,000 buildings were inspected and their data computerised by the Region during the emergency. Other inspections were carried out later by the technicians of the Marche Region, leading to a total number of 48,000 records. The survey was conducted on demand in both the epicentral and non epicentral areas, although it can be considered complete in some localities in the epicentral area.

In both Regions, public technicians inspected public buildings, professionals inspected residential houses and experts inspected churches and monumental buildings. In the latter case, representatives of the Ministry of Cultural Assets participated in the inspections. A short course (1-2 hours) was used to train inspectors. The survey of public buildings was managed by SSN and GNDT, and the survey of residential buildings was managed by the involved Regions.

The Marche '97 form was subsequently updated on the basis of the lessons learnt: the pre-formatted fields for the surface, number of stories and occupancy were made more precise and the damage description was updated to explicitly acknowledge the total absence of damage. In 1998 the revised form was used for the joint usability and damage assessment (second experience in Italy) after the Pollino earthquake, Southern Italy (September, 9, 1998, MI=5.5, 1 fatality). The survey was limited to the damaged buildings and the database contains about 20,000 records. Social workers, previously employed for vulnerability assessment, were trained with a short course (1-2 hours) and used for the survey.

After the Umbria-Marche 1997 and Pollino 1998 earthquakes, an action plan aimed at giving uniformity to the damage and safety assessment was started. The final version of the form has been delivered in 2000. Nevertheless much more has to be done in order to clarify the aim of the survey, the responsibilities of the technicians and the relationship between the damage survey and public funding for repair works. Furthermore all the Regions and the local Authorities involved in this activity should agree on the procedures and on the forms to be used, if these are to be, as it should be, the same for the whole country. SSN has organised, together with some Regions, a series of courses lasting about 5 days each, aimed at transferring the knowledge on these arguments. A long term goal of this action is to develop a registry of about one thousand, well trained, public technicians, to be used in case of emergency. A computer code, to give guidance to the technicians in the damage and safety assessment (Masiani, 1999; Gavarini, 1999; Decanini, 1999), has been developed by SSN, together with the University of Rome, and it has been used for training purposes.

COLLECTED DATA

It has been shown that the large number of buildings that need to be surveyed quickly in a post-earthquake usability and damage assessment is the main reason why only I-level accuracy data can be collected. Although the collected data cannot be used for an engineer assessment (II and III level), they can be statistically processed. Data concerning building identification are always necessary. In principle, when dealing with usability assessment, the only usability classification could be recorded and, similarly, when dealing with the direct economic loss, the only overall estimate of the repair cost could be recorded. However, in order to reduce the large subjectivity in usability assessment and in the repair cost estimate, an overall measure of damage or, better, the damage classification to different components, together with dimensional data, should be required. Building type is also useful when dealing with usability, repair cost or vulnerability functions, as it acts as a damage filter. Social data are finally useful to evaluate the earthquake impact. Data in the past, and at present, collected can be summarised as follows:

- Identification: Name, address, cadastral unit, photographs;
- Dimensional data: Mean surface, number of stories, height;
- Function: Property, function, percentage of use, number of dwellings and inhabitants;
- Building type: Materials, structural schemes, age of construction, maintenance, position;
- Soil condition: geomorphology, landslide;

- Building damage: damage levels and their extension in different components, overall measure of damage;
- Social data: homeless and families evacuated;
- Countermeasures; urgent barricades, already done or to be done;
- Quality of the inspection (complete, partial, from the exterior);
- Usability assessment;
- Notes

Data to be collected need to be easily determined by visual inspection. In this sense, the age of the building is not easily determined since it can only be obtained, during the emergency survey, by means of interviews either with the owners or with the tenants of the building. Definition of the data to be collected should be unambiguous and self-explained, data should be maximally informative of past and future seismic performance, useful for present methodologies and possible also for next future methodologies, finally interchangeable between I, II and II level accuracy. An accurate training is essential to reduce ambiguity in data collection. Ambiguity in data users should be avoided making use of proper data explanation. Forms should be easy to be filled and codification of the data should permit immediate check of the recorded data. The Italian form, reported at the end of the paper, has been specifically studied to this aim. This has not always been done in the past, as we will summarise in the following for the special case of building type and damage data collection.

Up to the present form, in order to classify the building component, a selection among different descriptions of the component material was required. In the early time of Friuli '76 earthquake, 3 vertical structure descriptions (stone masonry, brick masonry and columns) and 2 horizontal structure descriptions (RC floors with RC beams and all other type) were included in the form. As some important features of the load bearing system were not specified in the form (shape of stones, layout, ..), different building behaviours are expected for the same component description, questioning the data process. In Irpinia '80, an improved classification, including 5 vertical and 4 horizontal structure descriptions, was proposed (Figure 1).

Vertical structures		Horizontal structures	
Irregular stones	1	Vaults	1
Hewn stones	2	Wooden	2
Brick or square blocks	3	Steel	3
RC	4	RC	4
Mixt	5		

Figure 1. Building type classification used in Irpinia '80 survey

A few years later, Abruzzo '84, the number of different descriptions of vertical structures was increased up to 8 different vertical types (3 for stone masonry, 3 for brick masonry, RC and Mixt), while keeping the same description used in Irpinia for the horizontal structures. This process culminated with the GNDT I level form (Figure 2)

Vertical structures		Horizontal structures	
"A sacco" masonry	A	Wooden	A
"A sacco" masonry with strenghtenings	B	Wooden with iron ties	B
Hewn stone	C	Steel beams and bricks	C
Hewn stone with strenghtenings	D	Steel beams and bricks with iron ties	D
Round stone masonry	E	RC	E
Round stone masonry with strenghtenings	F	Vaults without iron ties	F
Tuff block masonry	G	Vaults with iron ties	G
Heavy concrete block masonry	H	Vaults and horizontal floors	H
Light concrete block masonry	I	Vaults and horizontal floors with ties	I
Brick masonry	L	Other	L
Hollow brick masonry	M		
Plain concrete shear walls	N		
RC shear walls	O		
RC bare frames	P		
Infilled RC frames (Weak infill)	Q		
Infilled RC frames (Strong infill)	R		
Steel	S		
Mixt	T		
Other	U		

281	B	3	C	2
285				
289				
293				
297				

Vertical Stair Horizontal Number

Figure 2. Building type classification in GNDT I level form

Although the form has 18 different types of vertical structures and 9 different types of horizontal structures, often ambiguity, inaccuracy and systematic errors happened. The classification based on component description highlights approximations when one attempts to use it in a context that is different from the expected one, due to the impossibility of listing all the different component descriptions. Moreover components with similar descriptions, can, sometimes, exhibit different seismic performances. Inspectors were required to classify the components on the basis of their only visual features, without any judgement on their seismic performance. Also the codification used in GNDT I level form was very complicate, relying on 4 characters (Figure 2), related to the type of vertical structural, type of stairs, type of horizontal structural and number of floor with same classification. The code, as for example B3C2 in figure 2, does not provide at first sight the selected building type.

In order to solve the above problems, in the current form it is required to select the component performance, instead of the component description, involving, thus, the inspector expert judgement in the component classification. The form also considerably simplifies the compilation and the check, as it refers to broad building classes, characterised by similar vulnerability and seismic performance. The preliminary version of the form, used in Marche Region after Umbra-Marche '97 is reported in figure 3. It is possible to note that for vertical structures, classification was based on component performance, while for horizontal structures was still based on component description.

Vertical Structures \ Horizontal structures		Masonry				Isolated columns	RC		Steel	Unknown
		Irregular layout or bad quality		Regular layout and good quality			Frame with soft story	Frame without soft story		
		Round stone without ties or beam ties	Round stone with ties or beam ties	Hewn stone or brick without ties or beam ties	Hewn stone or brick with ties or beam ties					
1	Vaults	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Yes			<input type="radio"/>	
2	Wooden	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>			<input type="radio"/>	
3	Steel and vaults	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>			<input type="radio"/>	<input type="radio"/>	
4	Steel	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>			<input type="radio"/>	<input type="radio"/>	
5	RC	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	No	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
6	Unknown	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	

Figure 3. Building type classification used in Marche Region after Umbria-Marche '97 earthquake

In the form, revised just in time for the Pollino '98 earthquake (Figure 4), the horizontal structure classification has been based on component performances. In addition the multiple answer option has been made clearer: when a circle is present a single answer is required, when a square is present, multiple answers are allowed. The RC and steel buildings classification has been improved making it possible to mix, making use of the multiple answer option, RC shear walls, RC frames and steel frames. The RC and steel classification probably has to be further developed in order to include sources of weakness like short columns, abrupt changes of mass/stiffness/capacity, misalignments, maintenance, bad quality material and so on.

Vertical Structures \ Horizontal structures		Masonry						Isolated columns	Mixt
		Unknown	Irregular layout or bad quality (Round stones, ...)		Regular layout and good quality (Hewn stone, brick,...)				
			Without ties or beam ties	With ties or beam ties	Without ties or beam ties	With ties or beam ties			
1	Unknown	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Yes	RC over masonry <input type="radio"/>	
2	Vaults without ties	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="radio"/>	Masonry over RC <input type="radio"/>	
3	Valut with ties	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="radio"/>	In horizontal <input type="radio"/>	
4	Flexible	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="radio"/>		
5	Semi-rigid	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="radio"/>		
6	Rigid	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="radio"/>		

R.c. or steel structures		
R.c. frames	<input type="checkbox"/>	
R.c. shear walls	<input type="checkbox"/>	
Steel frames	<input type="checkbox"/>	

REGULARITY		Irregular	Regular
		A	B
1	Plan and elevation	<input type="radio"/>	<input type="radio"/>
2	Cladding distribution	<input type="radio"/>	<input type="radio"/>

Figure 4. Building type classification used after Pollino '98 earthquake

The last revision of the form dates back to May 2000, when retrofitted or strengthened buildings were included in the classification. The form is enclosed at the end of this paper. It should also be noted that the form used in the Umbria Region, after the Umbria-Marche '97 earthquake, was more similar to Irpinia '80 and Abruzzo '84 (Figure 5).

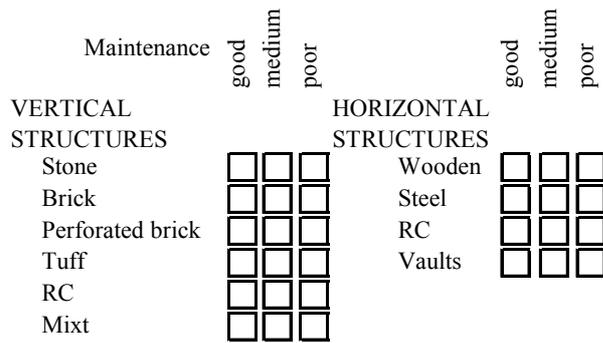


Figure 5. Building type classification used in Umbria Region after Umbria-Marche '97 earthquake

Concerning damage classification, as the visual inspection is the only possible technique to assess post-earthquake damage on a huge number of buildings, procedures and forms are usually required to record the observed damage. The severity of the observed damage is described by means of typical visible indicators such as cracks, deflections, changes of geometry, separations of elements, instability of RC bars, spalling, etc. All the damage classifications are articulated in degrees of severity and almost all use qualitative (type of damage) and quantitative (amplitude and extent) measures of damage.

In the Friuli '76 earthquake the aim of the damage survey was to assess the reparability of buildings and to estimate the economic loss. The form contained a specific part related to the cost of countermeasures. Damage was not assessed quantitatively, but with the following descriptions:

Destroyed

Not repairable

Repairable: Totally Partially Structural repair: yes no

Repair not required

Figure 6. Friuli '76 damage classification

The lack of a clear relationship between the damage description and a quantitative damage scale is one of the major difficulties encountered today when re-analysing the collected data.

The original damage scale used in the Irpinia 1980 survey consists of eight levels and is reported in table 4. The damage states are identified by quantitative measures of different types of damage. Damage is to be assessed for vertical structures, horizontal structures, roof, external walls, partitions and stair. In the form there is a strict relationship between damage, usability and actions to repair or demolish the building. Today a so strict relationship is not introduced in the form, because damage applies to each building component, while reparability and usability often applies to the whole building. Moreover partial collapse can be so localised that demolition may not be required.

Table 4. Damage levels in the 1980 Irpinia earthquake survey.

Level	Severity	Usability	Long-term countermeasures
1	None	Usable	None
2	Negligible	Usable	Repair not urgent
3	Slight	Usable	To be repaired
4	Noticeable	Partially usable	Repairable
5	Heavy	Unusable	Repairable
6	Very heavy	Unusable	To be demolished
7	Partial collapse	Unusable	To be demolished
8	Destroyed	Unusable	

After the Abruzzo 1984 earthquake, the damage survey was carried out using a 6 level scale. The damage is to be assessed for vertical structures, horizontal structures, roof, external walls, partitions, stair, projections and elevated objects. As in the case of Irpinia, information about damage extent was not collected explicitly because the extent of the damage was included in the degree of severity. In general the maximum observed damage is recorded for each component. As the damage classification is based on crack type (shear, flexural, etc.) and failure modes (in plane, overturning), a damage pattern categorisation was also required. It is described in figure 7. In table 5 the description of the damage states in the masonry bearing walls is reported. It can be seen that quantitative measures (e.g. crack amplitude) used for damage classification depend upon the residual strength and upon the risk associated with the

failure mode. For example a lower importance is attributed to flexural cracks near openings, often associated with local construction defects, or with non passing cracks, rather than with cracks associated with the complete separation of orthogonal walls or with crushing failures.

Table 5. Damage classification for masonry bearing walls used in the 1984 Abruzzo survey.

Level	Severity	Description
0	None	No visible damage
1	Slight	Cracks up to 1 mm
2	Relevant	Cracks up to 10 mm or up to 5 mm, when type 1-2-3 on more than 1/3 of the wall's surface.
3	Heavy	Cracks more than 10 mm wide or up to 10 mm, when type 1-2 between 1/3 and 2/3 of the wall's surface
4	Very heavy	Cracks type 1-8 up to 10 mm wide and on more than 2/3 of the wall's surface; leaning up to 50 mm with separation of floors; cracks type 1-8 40 mm wide on 1/3 of the wall's surface.
5	Destruction	

In the I level GNDT form, used after the Parma '83 and S. Lucia '90 earthquakes, the damage is articulated in six levels, from A to F. The inspectors have to identify the maximum damage, the damage with the highest extension together with its extension, the latter one expressed in 10 percentage classes. Damage assessment is performed at each floor and for the following building components: vertical structures, horizontal structures, stairs, partition and external walls. The damage description for each state is essentially the same as the Abruzzo '84 form and is summarised in table 6 for the masonry bearing walls. A section of the form is devoted to the damage to non-structural elements, in order to take into account their influence on economic loss and also on life-safety. The damage classification in the I level GNDT form is very precise, but relatively cumbersome to be assessed by non specialised personnel. Also the codification is not immediate as it requires for each floor with different damage a 4 character string as D4F2, being respectively the damage with the most extension, its extension, the most severe damage and the number of floors with the same damage classification.

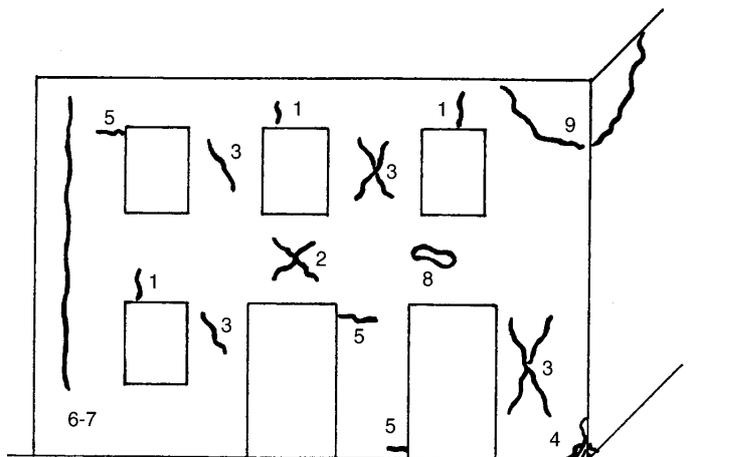


Figure 7: types of cracks in masonry bearing walls:

1) vertical cracks on openings; 2) diagonal cracks on parapets and on doors and windows lintels; 3) diagonal cracks on vertical walls between openings; 4) local masonry crushing with or without spalling; 5) horizontal flexural cracks on top or bottom of vertical walls between openings; 6) vertical cracks at wall intersections; 7) passing through vertical cracks at wall intersections; 8) spalling of material due to beam or floor pounding; 9) separation and expulsion of two corner walls.

Table 6. Masonry bearing walls damage classification (I level GNDT form).

Level	Severity	Description
A	None	No visible damage
B	Slight	Any crack up to 1 mm
C	Medium	Cracks up to 4 mm when types 1,5,6; up to 2 mm when types 2,3,7; up to 1 mm when types 4, 8 or 9.
D	Heavy	Cracks up to 10 mm when types 1,5,6; up to 5 mm when types 2,3,7; up to 1 mm when types 4, 8 or 9.
E	Very heavy	Cracks and damages higher than D.
F	Destruction	

The damage classification used in Marche Region after Umbria-Marche '97 earthquake is reported in the following

Figure 10. Damage classification in Pollino '98

ACTUAL PROCEDURES, FORMS AND TOOLS

In Italy, the current methodology for the usability and damage survey has been established in the second half of 90's. A first version of the damage and usability assessment form was produced just before the Umbria-Marche 1997 earthquake and was subsequently upgraded. A complete procedure for the technical operations concerning all the damage survey after an earthquake was then proposed (SSN-GNDT, 1998) and integrated in the general framework of the emergency management system of the Civil Protection Department (*Augustus method*: function n. 9). The procedure was submitted to politicians and to local administrations, responsible for the emergency management. In this way we expect that a large consensus on procedures and forms will be reached, contributing to a standardised emergency management system. The last revision, together with the field manual, is very recent (Baggio et al., 2000). The 3 pages form is reported at the end of the paper.

In emergency, building inspections are performed on citizen demand, addressed to the Mayor of the Municipality. Once the different requests, related to the same building, have been grouped, requests are redirected to one of the Centres for the management of the damage survey (COM), usually located in epicentral area. Surveyors inspect the buildings and results are delivered each day at the management Centre, where are computerised. On this basis, the list of inspected buildings and buildings to be inspected is updated. In case of high risk and if suggested by the inspectors, the Mayor of the Municipality promulgate evacuation decrees or limited use decrees. Countermeasures suggested by the inspectors, when inserted in the Mayor decree, are compulsory. Usually the Fire Brigades are in charge of countermeasures if public safety is involved. No posting system is adopted. In the reconstruction process, as financial contributions for the building strengthening depend on damage level, damage is assessed again, and in more detail, by professionals. The inspection on demand and the lack of posting system are the main reasons for multiple inspections on the same building.

It is useful to compare procedures and forms for damage collection in other countries all over the world. In Japan inspections are performed only on multi-owner buildings. Buildings to be inspected are selected after a rapid post-earthquake building screening. Due to the citizen's privacy, the results of usability inspections are to be considered, usually, just a suggestion for the citizens. A posting system, reflecting the building usability classification, is adopted. Once completed the usability assessment, the damage assessment is performed. In Kobe damage assessment has been performed sending to each inspector team a plan of the city containing the buildings to be inspected. The inspectors, after completed the damage collections, delivered to Building Research Institute the 1 page forms, already computerised. After the damage classification, the repair, upgrade or demolishing of the damaged buildings is suggested to the owner. The suggestion, unless public safety is involved, in not compulsory for the building owners. In Greece, usability assessment is performed on all the buildings located in urban centres in epicentral area, while it is performed on citizen demand outside the urban centres or in non epicentral area. Also in US the usability assessment is performed on demand. In both US and Greece, a posting system is used. In Greece the 1 page usability form is the same for quick and detailed evaluation, while in US a 1 page form is used for quick and a 2 pages form for detailed evaluation. In Turkey, damage data are recorded on a single page line for each building. Main differences in procedures and forms among Italy, Greece, Japan and Italy are reported in table 7 (Goretti, 2001, Goretti 2002).

Table 7. Main differences in forms and procedures between Italy, Greece and Japan

	Usability and damage evaluation	Inspections	Results of usability inspection	Posting	Numb. of pages in the form
Italy	Simultaneous	On citizen demand	Compulsory if a Mayor decree is promulgated	No	1 form, 3 pages
Greece	Only Usability	Every building in epicentral area, on citizen demand in non epicentral area	Compulsory	Yes	1 page form, same form for quick and detailed inspection
US	Only usability	On citizen demand	Compulsory	Yes	1 page form for quick inspection, 2 page form for detailed inspection
Japan	At different time	On previously selected buildings	Compulsory only if public safety is involved	Yes	2 forms, 1 page each

Besides procedures and forms, tools are necessary to speed up the procedures and to give immediate information on the earthquake impact. Up till now, the following tools have been developed and delivered:

- Software for the management of the inspections (National Seismic Survey, 2002);
- Software for the data computerisation and reports (National Seismic Survey, 2002);
- Software for economic loss estimate from dimensional, damage and typological data (Di Pasquale et al., 1998).

The necessary upgrading of the form after recent earthquakes (Marche '97, Pollino '98, present version) forced to frequently revise the above tools, leading to obvious significant difficulties.

DATA COMPUTERISATION, VALIDATION, MAINTENANCE, ARCHIVING AND DISSEMINATION

In Italy, data computerisation is performed by the involved Regions (by Prefectures in Turkey, by inspectors in Japan) in (almost) real time. Computerisation is a crucial item when buildings are inspected on request, due to the fact that, in order to avoid multiple inspections on the same building, the selection of the buildings to be inspected should be done from an up-to-date building list. Major problems have been encountered due to the fact that, sometimes, computerisation slow down the survey process. The computerised inspected buildings do not coincide with the actual inspected buildings and multiple inspection on the same building can arise.

The computerisation is funded by the Regions or by the National Civil Protection as item necessary for a proper reconstruction. The software for the computerisation should be delivered, once tested, before the event. It should include an error routine and all kind of possible reports, as usable and/or unusable buildings, homeless, proposed emergency measures, in each municipality or aggregated, performed in one day or cumulative, etc. When the software has not been immediately available, different field names, variables type (text, logic, number or variant) and classifications appeared in the computerisation.

Validation is another important step of the process. Repeated inspections on the same buildings due to multiple shocks are expected, however very often erroneous repeated inspections to the same buildings arose due to buildings with more than one entrance, to buildings with more than one request, to non effective computerisation of the already inspected buildings, to inspections erroneously performed on dwellings instead of on buildings. Validation is performed by the involved Regions and funded by Regions or National Civil Protection, again as an item necessary for a proper reconstruction. Validation takes long time and it is usually performed with the aid of damage maps and making use, if possible, of the same inspectors used in the damage survey. In passing note that validation is required mainly because inspections are performed on request.

Once computerised and validated, data are acquired by National Seismic Survey, where are also maintained⁴.

The updating of the data is not relevant for post-earthquake damage collected data. It is however relevant in case of pre-event survey, when dealing with the inventory. As in Italy pre-event survey are relatively recent (1996-1998), there is no need, today, to update the data. At the same time, a maintenance plan has not been established for the future. It is surely an high cost program and it is not clear which institution is in charge of and who will fund the updating of the collected data. Another non negligible item in data maintenance is the updating of the media where data are recorded, as new technologies require new media every few years.

Dissemination and access is the final issue of data collection. In order to codify the access to data, final users should be known (Universities, local governments, insurance companies, private companies) together with the purpose (Researches, emergency plans, risk and scenario assessment, outsourcing), the required data (name, localisation, damage levels, usability classification) and the level of aggregation of the data. Obviously privacy should be guaranteed avoiding that the single property could be detected, as damage and vulnerability data could also be used to lower the building value on the market. Up to now in Italy there has been very few application for the collected data. This does not mean that these data are not be used, as in fact they are by SSN and by some Universities. The absence of applications is mainly due to the lack of attention to these themes. The insurance market is not well developed and many jurisdictions, mainly in high risk Southern Italy, are so overwhelmed by ordinary emergencies that are not able to be active in prevention and emergency management. Consequently, also very few private company are involved in scenario and risk analysis.

CONCLUSION

The high value of the post-earthquake data, as real data, opposed to laboratory data, has always been well recognised. Post-earthquake data are invaluable in establishing plausible prevention plans (risk assessment, seismic codes, action plans for risk reduction) and a reasonable emergency management (seismic scenarios for emergency plans, repair cost estimate). A proper data management, (collection, maintenance, diffusion) is also important to augment the value of the data, while preserving the privacy. From the above consideration it appears that an action plan aimed to post-earthquake damage collection should be funded, planned and maintained before the event.

In this framework, an outline of the Italian experiences in the field of damage assessment has been presented. Resolved, but also not yet resolved problems, encountered in assessing procedures, forms, tools, computerisation, validation, maintenance, and data dissemination, have been highlighted.

Although Italy has a long history in post-earthquake damage evaluation, systematic damage data collection started only in the '70. Since then, different forms and procedures has been used. The major source of damage data has always been the post-earthquake usability and damage survey. The overall damage in the municipality, taken into

⁴ Very recently the Department of Civil Protection has been reorganized, with SSN as an Office. It is not clear, at the moment, if the centralization of databases will remain or not.

account in the macroseismic assessment and at present not recorded, can be another source of data, useful for real time scenario updating.

The recent Umbria-Marche '97 earthquake gave rise to an action plan aimed to uniform usability and damage assessment procedures and forms, to train the inspector teams and to provide tools to manage inspections and to computerise and process the collected data.

The high number of buildings to be inspected in post-earthquake usability and damage evaluation allow only for I level data collection. Nevertheless collected data all over the world vary considerably, owing to the different purposes of the damage assessment. Major drawbacks in Italy come from the survey on demand, as it causes biased samples and multiple inspections on the same buildings. Collected data are later computerised with predefined tools and then validated. In order to avoid some of the above difficulties, it is proposed to perform the survey on every building in epicentral area and on request on non epicentral area. Moreover, the use of GIS systems and pre-event database will speed up the damage assessment, the computerisation and the validation of the data.

After the emergency phase, during the reconstruction process, the completion of the damage data should be made, in order to reduce the bias of the samples. At the same time the detailed damage collection (III level) on a reduced set of buildings should be performed.

The reliability of the data come from unambiguous terms in the form and from well trained inspectors. Forms with multiple choice and multiple answers seems to perform better. As an example the answer "none" should always be present in the form and not deduced from the fact that no answer is marked. Similarly the component performance should be preferred to the component description. The accuracy of the collected data is related to the accuracy of the inspection, and, to this end, buildings should not be inspected by the only building exterior.

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1° LEVEL FORM FOR POST-EARTHQUAKE DAMAGE AND USABILITY ASSESSMENT AND EMERGENCY MEASURES IN RESIDENTIAL BUILDINGS

(AeDES 05/2000)

Request code

SECTION 1 Building identification Province: _____ Municipality: _____ Locality: _____ Address 1 <input type="radio"/> Street _____ 2 <input type="radio"/> Road _____ 3 <input type="radio"/> Alley _____ 4 <input type="radio"/> Square _____ Number _____ 5 <input type="radio"/> Other _____ (Indicare: contrada, località, traversa, salita, etc.)	INSPECTION DATA Surveyor _____ day _____ month _____ year _____ Form n. _____ Date _____	
	1.1. IDENTIFICATIVO EDIFICIO Istat Reg. _____ Istat Prov. _____ Istat Municip. _____ Aggregate num. _____ Building num. _____ _____	
	Istat Locality code _____ tipo carta _____ Istat Census code _____ ° carta _____	
	Land Register Foglio _____ Allegato _____ Particelle _____	
	Building location 1 <input type="radio"/> Isolated 2 <input type="radio"/> Internal 3 <input type="radio"/> End 4 <input type="radio"/> Corner	
Building name or owner name _____	Code Use _____	

Sketch of structural aggregate and building location

SECTION 2 Building description		Age		Use		Occupants																																		
Metrical data		Age		Use		Occupants																																		
Total number of stories	Average interstory height [m]	Average floor area [m ²]	Construction age and strengthening [max 2]	Use	Num. of units in use	Utilisation in percentage	Occupants																																	
<input type="radio"/> 1 <input type="radio"/> 9 <input type="radio"/> 2 <input type="radio"/> 10 <input type="radio"/> 3 <input type="radio"/> 11 <input type="radio"/> 4 <input type="radio"/> 12 <input type="radio"/> 5 <input type="radio"/> >12 <input type="radio"/> 6 <input type="radio"/> 7 <input type="radio"/> 8	<input type="radio"/> ≤ 2.50 <input type="radio"/> 2.50 ÷ 3.50 <input type="radio"/> 3.50 ÷ 5.0 <input type="radio"/> > 5.0 Undergr. stories <input type="radio"/> 0 <input type="radio"/> 2 <input type="radio"/> 1 <input type="radio"/> ≥ 3	<input type="radio"/> ≤ 50 <input type="radio"/> 400 ÷ 500 <input type="radio"/> 50 ÷ 70 <input type="radio"/> 500 ÷ 650 <input type="radio"/> 70 ÷ 100 <input type="radio"/> 650 ÷ 900 <input type="radio"/> 100 ÷ 130 <input type="radio"/> 900 ÷ 1200 <input type="radio"/> 130 ÷ 170 <input type="radio"/> 1200 ÷ 1600 <input type="radio"/> 170 ÷ 230 <input type="radio"/> 1600 ÷ 2200 <input type="radio"/> 230 ÷ 300 <input type="radio"/> 2200 ÷ 3000 <input type="radio"/> 300 ÷ 400 <input type="radio"/> > 3000	<input type="checkbox"/> ≤ 1919 <input type="checkbox"/> 19 ÷ 45 <input type="checkbox"/> 46 ÷ 61 <input type="checkbox"/> 62 ÷ 71 <input type="checkbox"/> 72 ÷ 81 <input type="checkbox"/> 82 ÷ 91 <input type="checkbox"/> 92 ÷ 01 <input type="checkbox"/> ≥ 2002	<input type="checkbox"/> Residential <input type="checkbox"/> Production <input type="checkbox"/> Business <input type="checkbox"/> Offices <input type="checkbox"/> Public <input type="checkbox"/> Storage <input type="checkbox"/> Strategic <input type="checkbox"/> Turistic	_____ _____ _____ _____ _____ _____ _____	<input type="radio"/> > 65% <input type="radio"/> 30 ÷ 65% <input type="radio"/> < 30% <input type="radio"/> Non in use <input type="radio"/> In constr. <input type="radio"/> Unfinished <input type="radio"/> Abandon	<table border="1"> <tr> <th>100</th> <th>10</th> <th>1</th> </tr> <tr> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>1</td> <td>1</td> <td>1</td> </tr> <tr> <td>2</td> <td>2</td> <td>2</td> </tr> <tr> <td>3</td> <td>3</td> <td>3</td> </tr> <tr> <td>4</td> <td>4</td> <td>4</td> </tr> <tr> <td>5</td> <td>5</td> <td>5</td> </tr> <tr> <td>6</td> <td>6</td> <td>6</td> </tr> <tr> <td>7</td> <td>7</td> <td>7</td> </tr> <tr> <td>8</td> <td>8</td> <td>8</td> </tr> <tr> <td>9</td> <td>9</td> <td>9</td> </tr> </table>	100	10	1	0	0	0	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9
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9	9	9																																						
				Ownership A <input type="radio"/> Public B <input type="radio"/> Private																																				

SECTION 3 Building Type (multi-answer; max 2.)

		Masonry buildings								R.c. or steel structures			
		Unknown	Irregular layout or bad quality (stones, pebble,...)		Regular layout and good quality (Hwen stones, bricks,...)		Isolated columns	Mixt	Strengthened	R.c. frames		<input type="checkbox"/>	
			Without ties or tie beams	With ties or tie beams	Without ties or tie beams	With ties or tie beams				R.c. shear walls		<input type="checkbox"/>	
										Steel frames		<input type="checkbox"/>	
Vertical structures		A	B	C	D	E	F	G	H	REGULARITY			
Horizontal Structures										Irregular	Regular		
										A	B		
1	Unknown	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	SI	<input type="checkbox"/>	<input type="checkbox"/>	1	Plan and elevation	<input type="radio"/>	<input type="radio"/>
2	Vaults without ties	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="radio"/>	G1	H1	2	Cladding distribution	<input type="radio"/>	<input type="radio"/>
3	Vaults with ties	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>				
4	Flexible floors	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	NO	G2	H2				
5	Semirigid floors	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="radio"/>	<input type="checkbox"/>	<input type="checkbox"/>				
6	Rigid floors	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		G3	H3				

Roofs		
1	<input type="radio"/>	Heavy and thrusting
2	<input type="radio"/>	Heavy and non thrusting
3	<input type="radio"/>	Light and thrusting
4	<input type="radio"/>	Light and non thrusting

SECTION 4 Damage to Structural Elements and existing emergency measures

Damage level and extension		DAMAGE ⁽¹⁾										EXISTING EMERGENCY MEASURES							
		D4-D5 Very Heavy			D2-D3 Severe			D1 Light			Null	None	Removal	Ties	Repair	Propping	Barrier or protection		
		> 2/3	1/3 - 2/3	< 1/3	> 2/3	1/3 - 2/3	< 1/3	> 2/3	1/3 - 2/3	< 1/3									
																		A	B
1	Vertical structures	<input type="checkbox"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>														
2	Horizontal structures	<input type="checkbox"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>														
3	Stairs	<input type="checkbox"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>														
4	Roofs	<input type="checkbox"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>														
5	Claddings and partitions	<input type="checkbox"/>	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>														
6	Pre-existing damage	<input type="checkbox"/>	<input type="radio"/>																

(1) - The damage extension must be filled only if the corresponding damage level is present in the building.

SECTION 5 Damage to Non-structural Elements and existing emergency measures

Damage		PRESENT	EXISTING EMERGENCY MEASURES							
			None	Removal	Propping	Repair	No entry	Barrier or protection		
			B	C	D	E	F	G		
1	Falling of plaster, coverings, false-ceilings	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>						
2	Falling of tiles, chimneys...	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>						
3	Falling of ledges, parapets, canopies	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>						
4	Falling of other internal or external objects	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>						
5	Damage to hydraulic or sewage plant	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>						
6	Damage to electric or gas plant	<input type="radio"/>	<input type="radio"/>	<input type="checkbox"/>						

SECTION 6 Falling objects from other buildings and existing emergency measures

Cause		Risk on			Existing emergency measures	
		Building	Entry road	Lateral roads	No entry	Barriers or passing protection
		A	B	C	D	E
1	Object falling from adjacent buildings	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Lifelines damage	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SECTION 7 Soil and Foundation

SITE MORPHOLOGY				DAMAGE (present or possible): <input type="checkbox"/> Slopes <input type="checkbox"/> Foundation Soil											
1 <input type="radio"/>	Top	2 <input type="radio"/>	High slope	3 <input type="radio"/>	Mild slope	4 <input type="radio"/>	Plain	A <input type="radio"/>	Absent	B <input type="radio"/>	Produced by eqk.	C <input type="radio"/>	Worsened	D <input type="radio"/>	Preexistent



APPENDIX F

NOTES AND SUMMARY RECOMMENDATIONS FROM WORKSHOP WORKING GROUPS— ELECTRONIC APPENDIX

This appendix is in electronic format, on the accompanying CD to this report. Contact EERI for additional copies of the CD. It contains summary discussion and recommendations from the various working groups at the Pasadena workshop.

Contents:

Working Groups 1 and 4 assignments (by discipline: social science, built environment, earth sciences, systems and lifelines, modelers and insurers)

Working Group 2 assignments (type of organization: government, academic, commercial)

Working Group 3 assignments (mix of organizations and disciplines)

Notes from Working Group 1 and 4: Modelers and Insurers

Notes from Working Group 1 and 4: Social Scientists

Notes from Working Group 1 and 4: Lifelines

Notes from Working Group 2: Academics

Notes from Working Group 2: Commercial

Notes from Working Group 3: Group A

Notes from Working Group 3: Group B

Notes from Working Group 3: Group C

Summary Presentation from Built Environment Group

Summary Presentation from Earth Sciences Group

Summary Presentation from Social Sciences Group



APPENDIX G

LEARNING FROM EARTHQUAKES: A SURVEY OF SURVEYS—ELECTRONIC APPENDIX

Keith A. Porter, M.EERI

This appendix is in electronic format, on the accompanying CD to this report. Contact EERI for additional copies of the CD. It contains supporting material presented with Porter, K.A., 2003, “Learning from Earthquakes: a Survey of Surveys,” keynote paper (Appendix D). It is best read in Adobe Acrobat for viewing bookmarks and bibliographic references.

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(KAP) G.W. Housner Senior Research Fellow, California Institute of Technology, Pasadena, CA 91125-4400