14.

Real-Time Loss Estimation as an Emergency Response Decision Support System: The Early Post-Earthquake Damage Assessment Tool (EPEDAT)

Ronald T. Eguchi, M.EERI, James D. Goltz, M.EERI, Hope A. Seligson, M.EERI,
Paul J. Flores, Neil C. Blais, Thomas H. Heaton, M.EERI, and Edward Bortugno

At the time of the Northridge earthquake, a number of new technologies, including real-time availability of earthquake source data, improved loss estimation techniques, Geographic Information Systems and various satellite-based monitoring systems, were either available or under consideration as emergency management resources. The potential benefits from these technologies for earthquake hazard mitigation, response and recovery, however, were largely conceptual. One of the major lessons learned from the January 17, 1994 earthquake was that these technologies could confer significant advantages in understanding and managing a major disaster, and that their integration would contribute a significant additional increment of utility. In the two and half years since the Northridge earthquake, important strides have been taken toward the integration of relatively discrete technologies in a system which provides real-time estimates of regional damage, losses and population impacts. This paper will describe the development, operation and application of the first real-time loss estimation system to be utilized by an emergency services organization.

INTRODUCTION

The Northridge earthquake was the first earthquake disaster to occur in the United States in which important emergency response and early recovery decisions were based on loss estimates as well as actual data gathered through standard reconnaissance procedures. The utilization of loss estimation techniques in the immediate post-earthquake context is a key development and marks a significant departure from conventional applications. For the last two decades, earthquake loss studies have addressed the pre-earthquake planning needs of utility operators, the insurance industry and government emergency response agencies. Although the needs of these users vary, understanding risks and maintaining public safety

---

(RTE), (JDG), (HAS), (PJF), and (NCB), Center for Advanced Planning and Research, EQE International, Inc., 18101 Von Karman Ave. #400 Irvine, CA 92612
(THH),Department of Engineering Seismology, California Institute of Technology, Mail Code 252-21, Pasadena, CA 91125
(EB),Rick Management Branch, Governor's Office of Emergency Services, 1300 Clay Street #400, Oakland, CA 94612

©Earthquake Spectra, Volume 13, No. 4, November 1997

have generally required similar scenario events, that is, those with the greatest impacts on the local population and economy.

Historically, loss estimation studies have identified individual scenario earthquakes as the basis for planning (ATC, 1996; Algermissen et al, 1988; CDMG, 1982a, 1982b, 1987, 1988b, 1990a, 1995; Dames and Moore, 1996; EQE, 1997; FEMA/CUSEPP, 1985; Harlan and Lindbergh, 1988; NOAA, 1973.). These studies use existing knowledge of regional geology and seismology to generate maps with estimated intensities or accelerations and, based on projected ground motions and other factors, estimate damage to structures and lifelines, and impacts on population. Some studies also address potential secondary hazards such as fire, flood and hazardous materials releases. Presented in report or document form, often with fold-out and sometimes overlay maps, these earthquake scenarios have been employed by government and utilities to prepare for and mitigate damage from large events. Thus, the typical loss study has been single-event focused, applied in the long-term pre-event period and utilized primarily by those concerned with seismic safety planning and risk management.[1]

Even before the Northridge earthquake, technological developments were rapidly rendering these scenarios and the formats in which they are presented obsolete. The advent of high speed computing, satellite telemetry and Geographic Information Systems (GIS) have made it possible to electronically generate loss estimates for multiple earthquake scenarios, provide a nearly unlimited mapping capability, and perhaps most important, develop estimates for an actual earthquake in near real-time given the source parameters of an event, i.e., magnitude and location. For the last five years, real-time broadcasts of earthquake data including magnitude, location, depth and time of occurrence, have been available in southern California on an experimental basis from the Southern California Seismic Network operated jointly by the California Institute of Technology and the U. S. Geological Survey.

Concurrent with the development of the Caltech-USGS Broadcast-of-Earthquakes (CUBE) System, EQE International, Inc. was retained by the Governor's Office of Emergency Services to design a GIS-based system capable of modeling building and lifeline damage and estimating casualties in real-time given the source parameters of an earthquake from CUBE (Eguchi, et al, 1994). Triggered by receipt of magnitude and location coordinates from CUBE, the Early Post-Earthquake Damage Assessment Tool (EPEDAT) utilizes fault and seismicity data to locate the most likely source of an earthquake. Applicable ground motion and soil amplification models are then employed to estimate the expected intensity patterns in the affected area. These intensities are then overlaid onto the computerized data files containing an aggregate listing of buildings and lifelines in the region. Based on damage and casualty models and the intensity patterns computed, building and lifeline damage as well as casualties are estimated for the impacted area.

In the remainder of this paper, we will explore the basic methodology employed in EPEDAT, software specifications and the major applications of the system. In the

---

[1] One study which shows the (discounted) value of "cumulative damage" throughout the San Francisco Bay area is ABAG Earthquake Mapping Project, Working Paper #17, using Earthquake Intensity and Related Damages, June 1982.

concluding section, future applications will be explored as well as the potential utility of an integrated real-time information system capable of providing a new level of decision support for emergency responders in the critical minutes and hours following a major damaging earthquake.

METHODOLOGY

The methodology for estimating early post-earthquake damage, losses and population impacts consists of several steps, some of which are interactive. Since the objective of this procedure is to provide the best estimate of damage based on all available data, including post-earthquake information, steps which compare or calibrate estimates with actual field data are essential elements of the methodology. In general, these iterative loops involve refining estimates of earthquake source parameters or modifying damage algorithms for buildings and contents. The basic methodology for estimating early post-earthquake damage is presented in Figure 1. Seven essential steps are described below.

REAL-TIME SEISMIC INFORMATION FROM CUBE

The basic input data for EPEDAT consists of earthquake magnitude, epicenter location, and as available, measurements of regional peak ground accelerations. The source for this information is the Caltech-USGS-Broadcast-of-Earthquakes (CUBE) program which provides earthquake magnitude and location information from the Southern California Seismic Network to participating organizations through a commercial paging system within minutes of an earthquake. This program, which was initiated in 1992, currently has over twenty participants including water, power, gas and telephone utilities, railroads and state and local offices of emergency services.

The CUBE system works in the following manner: when an earthquake occurs, the event is recorded on a network of seismometers. These instruments (roughly 200 located throughout the southern California area) locate more than 10,000 earthquakes every year (CUBE, 1992). These data, in the form of seismograms, are telemetered to a central processing site at Caltech (via phone lines and radio) where earthquake magnitude and location data are determined automatically. These processing units are called real time processors (RTP) and CUSP units. In addition to the instruments that are part of the Southern California Seismic Network, a second set of broadband seismometers (10 Hz to DC) also record data from the earthquake and telemeter this information (via satellite) to Caltech.

For large events, the processed data is checked by the seismologist on call at the Seismological Laboratory at Caltech. Once the information has been verified for accuracy, these data are sent via modem or radio to a commercial paging system that relays information to individual pagers. The processed data may be observed via the pager system, or it may be input directly into a computer system where the magnitude and location of the event are displayed on a CUBE-developed software screen (CUBE, 1992). This last medium, the Q-Pager system is the one in which EPEDAT functions

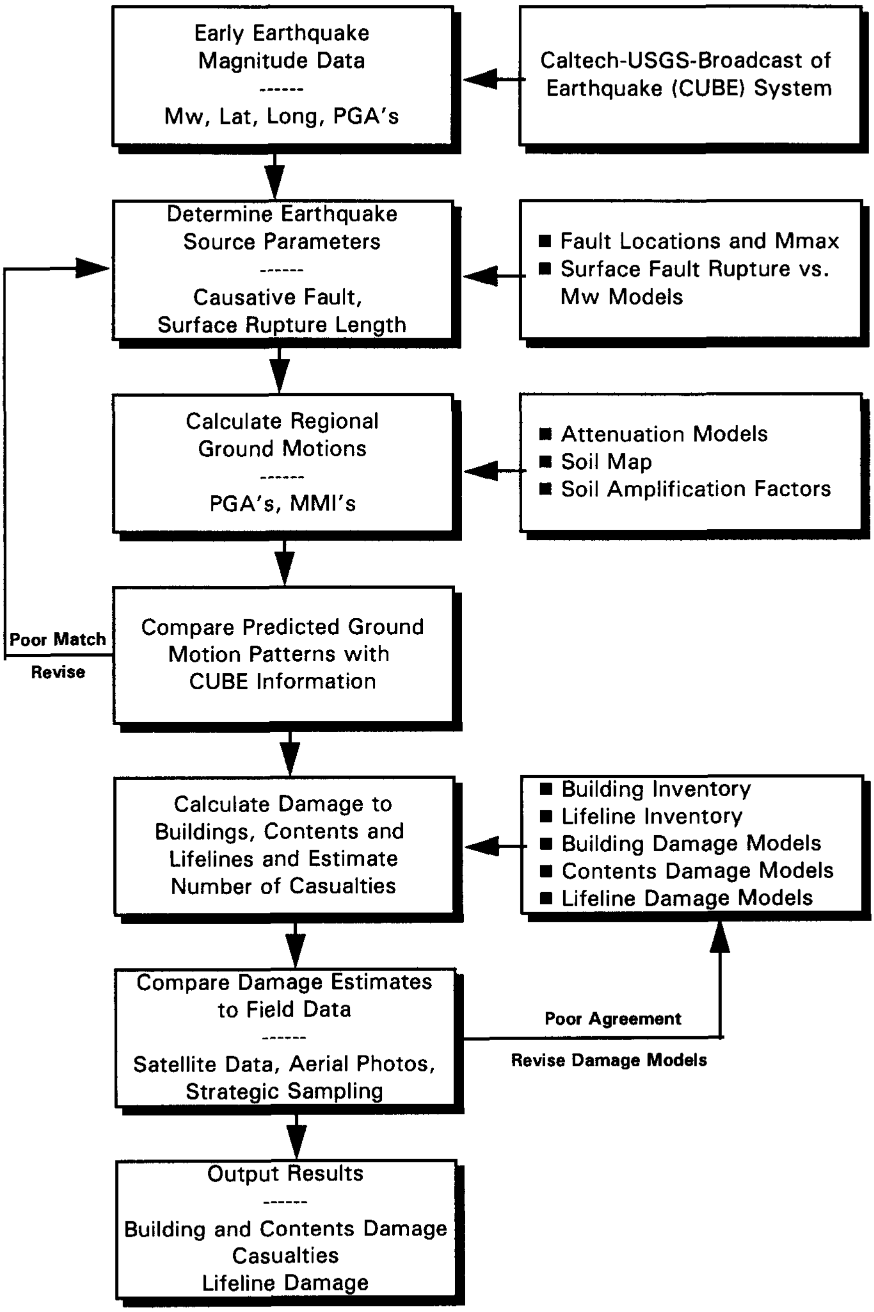


Figure 1. Methodology for Estimating Early Post-Earthquake Damage

FAULT DETERMINATION

The second step is to identify the causative fault and to estimate the extent of fault rupture. It is important to estimate fault rupture lengths and their locations since ground motion patterns will depend on the distance to the fault rupture plane. Knowledge of rupture length is critical for large earthquakes that generate long or multiple segment ruptures. Smaller events may be modeled as point sources with little or no linear rupture length.

One of the more important tasks associated with this step is identification of the causative fault. In southern California, where fault systems are complex, it may be difficult to initially determine the causative fault. This identification is further complicated by the presence of faults that do not break the surface or "blind thrust" faults. During the Northridge earthquake, for example, it took several days after the earthquake to finally identify the causative fault system and its mechanism of failure.

To address this issue of fault assignment, we have developed the following procedure. A complete list of known active faults has been compiled and their locations have been digitally input into EPEDAT. For the most part, these are faults that have been identified as active or potentially-active by the California Division of Mines and Geology (CDMG, 1988a, 1990b, 1994). In addition, known blind thrust ramps have been added to the database as three-dimensional models.

Next, we have developed a model which recognizes the maximum magnitude potential of each fault and its area of influence (i.e., zone of possible earthquake occurrence). The area of influence is based on knowing the type of fault (e.g., strike-slip, reverse, thrust); the largest earthquake that can be generated by the fault; and the location of associated fault segments. Based on these data, areas are drawn around each fault. When an earthquake is recorded, the location of the event is overlaid onto these areas. If the earthquake falls within one area of influence and the recorded magnitude is less than the maximum magnitude for that fault, the earthquake is assigned to that fault. If the earthquake falls within several areas of influence, a check is made regarding the maximum magnitudes for the possible causative faults. If the observed magnitude is below the maximum for each fault, then the shortest distance between the epicenter and each fault is used as a determining factor. If these distances are the same for each candidate fault, then a final determination of the causative fault is made by comparing projected ground motion levels from each fault to actual accelerograph measurements and selecting that fault which produces the smallest overall differences. This step is discussed in more detail in the next section. With respect to projected fault rupture lengths, these parameters are computed from the magnitude data. Different models are used to determine fault rupture lengths depending upon fault type.

REGIONAL GROUND MOTION INTENSITIES

The next step involves the calculation of regional ground motion intensities. Based on the magnitude of the earthquake, the location of the projected fault rupture area or length, and the type of local soil conditions, ground motions are computed for a predetermined grid system. Currently, ground motion intensities are measured by two parameters: Modified Mercalli intensity and peak ground acceleration. In the future, other measures of instrumental intensity including peak ground velocity, or spectral ordinates for selected frequency ranges, may be calculated.

As is characteristically done in most seismic hazard calculations, intensities are modified for each site based on local soil or geologic conditions. These factors are incorporated in the ground motion attenuation equation which considers the effects of source type, earthquake size and local soil amplification. Currently, the equation that is used by EPEDAT to estimate ground motions for southern California is the Campbell and Bozorgnia (1994) relationship. This equation incorporates earthquake magnitude, fault type, distance to the fault plane and soil type as parameters. The equation for peak ground acceleration on alluvium is given below.

$$\ln(PGA) = -3.512 + 0.904M - 1.328\ln\sqrt{R_s^2 + [0.149\exp(0.647M)]^2}$$
$$+[1.125 - 0.112\ln(R_s) - 0.0957M]F \tag{1}$$

where PGA is peak ground acceleration (g); M is earthquake moment magnitude, R_S is the closest distance to the seismogenic rupture (km), $F = 0$ for strike-slip and normal faulting earthquakes and 1 for reverse, reverse-oblique, and thrust faulting earthquakes.

Since we are interested in estimating Modified Mercalli intensities at this point, a conversion equation between MMI and PGA is needed. For this purpose, we have chosen to use Trifunac's (1976) equation. This equation, converted to units of g, is given below.

$$MMI = a_1 + a_2 \ln PGA \tag{2}$$

where a_1 and a_2 are equal to 10.5 and 1.48, respectively.

In order to account for variations in local ground conditions from firm alluvium, MMI modifiers were subtracted from the baseline alluvium MMI values. These modifiers were based on Evernden and Thomson's (1988) site soil classifications and local soil information. Local soil information for the southern California region is available in computerized form, sampled on a half-minute basis. MMI values may vary with local ground conditions as much as 1-1/2 units for sites located the same distance away from a given magnitude event. "Soft" (unconsolidated) soil sites show the largest response, while "hard" (usually older, consolidated) soil or rock sites show the smallest response, decreasing the response by 1-1/2 MMI units. These modifiers are presented in Table 1.

CALIBRATION OF PROJECTED INTENSITIES WITH POST-EARTHQUAKE DATA

At this point in the analysis, a comparison is made between the ground motions calculated based on the attenuation model and those which are actually observed during the earthquake. As stated earlier, the CUBE system will produce early data on peak ground accelerations from the earthquake. When available, this data can be used to check, calibrate and perhaps even modify (in near-real time) the ground motion attenuation models contained within EPEDAT. For example, if the post-earthquake acceleration data appears to be biased towards higher ground motions (i.e., higher than normal), adjustments to the EPEDAT attenuation model can be made and regional motions recalculated. The more stations that are supplying accelerograph data to make these checks, the better the chance that unique ground motion patterns will be observed during the event. If no major changes are necessary in modeling the intensity patterns from the earthquake, then the analysis proceeds to the next step.

Table 1. Site geology and relative MMI increments

Class	Description	Relative MMI Increment
A	Granitic and Metamorphic Rock	-1.5
B	Paleozoic Sedimentary Rock	-1.5
C	Early Mesozoic Sedimentary Rock	-1.2
D	Cretaceous-Eocene Sedimentary Rock	-0.8
E	Undivided Tertiary Sedimentary Rock	-0.7
F	Oligocene-Pliocene Sedimentary Rock	-0.5
G	Pliocene/Pleistocene Sedimentary Rock	0.0
H	Tertiary Volcanic Rock	-1.2
I	Quarternary Volcanic Rock	-1.2
J,L	Quaternary Sedimentary Deposits	0.0

DAMAGE ASSESSMENT

At this point, it is possible to estimate regional damage to exposed facilities. In order to do this, several models must be inserted, the most important of which are the exposure models. In general, there will be three sets of exposure models: buildings and contents, exposed populations, and lifelines. In addition to the exposure models, damage models for buildings and contents, and casualty models for exposed populations must be employed.

We have incorporated exposure models that have been developed from county assessor's data for buildings, and census and employment data for exposed populations. EPEDAT currently has information for the following counties in southern California:

Los Angeles
Riverside
San Bernardino
Ventura
Orange

The estimation of damage and casualties follows basic damage equations. In general, the following equation is used:

$$\text{Damage} = E[\text{Damage} \mid \text{Intensity}] \tag{3}$$

where *E*[ ] represents the expected or mean value of damage given a particular intensity level. That is, once the intensity is known for a particular site, the appropriate damage algorithm is selected and damage is estimated based on the observed intensity. Equation (3) is generally referred to as a damage function or algorithm. The development of these damage algorithms may follow two separate methods. The first set of models is constructed based on expert opinion. ATC-13 (ATC, 1985) is a good example of this type of development. The major benefit in using such an approach is that individual relationships can be developed for a wide range of building types without much empirical data. Since their development is based on subjective opinions, basic trends can be developed or postulated for general facility types. Also, the judgment of experienced engineers can be used to help guide these relationships. The drawback of this approach is that these models may or may not replicate actual earthquake damage experience since little data are used to construct these relationships.

A second set of models results from empirical analysis of past earthquake data. If large data sets are available to construct statistical models, this results in the most realistic representation of damage behavior. Unfortunately, these large data sets exist only for a few general construction categories. The most robust data set exists for single-family, wood-frame construction. As the Northridge earthquake points out, however, the largest contributor to total losses is damage to residential construction.

EPEDAT currently uses a combination of the above models. For wood-frame construction, actual earthquake data and models developed from this data are used. For other construction types, the results from the ATC-13 survey are used directly, and in some cases refined to reflect knowledge of local construction practices. Hopefully, these subjective models can be enhanced based on the introduction of new data (e.g., the Northridge data).

EPEDAT uses the results from the building damage analysis to project impacts on exposed populations. Casualties are estimated by knowing the population levels within certain building types, and the extent of estimated building damage. Other impacts, such as displaced populations, are also calculated as a function of building damage.

COMPARISON OF DAMAGE PROJECTIONS WITH POST-EARTHQUAKE DATA

At this point in the analysis, a comparison can be made between estimated damage levels and observed post-earthquake damage data. Several techniques are being developed that will enhance our ability to calibrate regional damage after major events. Techniques being developed at the Jet Propulsion Laboratory (JPL) in Pasadena use satellite data and information to identify areas of massive ground movement (Crippen, 1992). By comparing pre- and post-earthquake satellite photos of the affected area, scientists at JPL have successfully identified areas of surface fault rupture. This technique was applied successfully using data from the 1992 Landers earthquake in southern California. In a more refined application of these techniques, areas of liquefaction, ground movement or landslide could perhaps be identified. This information would be particularly useful in identifying areas of potential damage to underground utility systems.

The use of aerial photos can also help establish levels of regional damage. Hamada and O'Rourke (1992) have shown that aerial photos are extremely useful in identifying the magnitude and direction of significant land movements caused by liquefaction ground failure. This approach can also be used to calibrate specific predictions of site intensity by comparing the effects at sites with known seismic vulnerabilities to field observation data.

Finally, a new technique being developed by EQE is a rapid sampling scheme whereby predetermined sites or areas can be established within the southern California that will allow a limited but statistically significant sampling of post-earthquake damage. This approach is similar to the "Gallup Poll" or exit poll methodologies that are used to project "winning candidates" based on limited polling of voters. In the voter polls, demographic data plays an important element in the projections; in the damage assessment procedure, building inventory data plays a key role.

Using post-earthquake damage data collected from various sources, it is then possible to compare damage projections with actual field data. If the comparisons are not good, then modifications to the damage models must be made, in a manner similar to the changes needed to better project ground motion intensities. By incorporating this iterative step in the methodology, the procedure becomes dynamic, in the sense that new data are always being incorporated to improve the model predictions. As is evident from the recent Northridge earthquake, there are always surprises that occur, either in observed levels of ground motion or building damage. For an early post-earthquake damage assessment tool to be effective, it must incorporate the ability to merge actual data observed during the event into the analysis. In the ideal case, this process should span over the first few days of the disaster. More discussion on this topic is provided in a later section (The Northridge Earthquake).

OUTPUT OF RESULTS

The final step involves the output of damage and casualty results. The most important factor here is to output the information in a form that can be input into a Geographical Information System (GIS). After a major disaster, many types of data must be displayed to help make decisions. The Northridge earthquake showed the value of having a versatile GIS system. Important data, such as building damage, sheltered populations, and people needing aid were all displayed graphically using a GIS system. This information, when combined with a listing of resources, allowed a more effective match of need versus resource. In the future, GIS can be used in a more comprehensive way to decide on resource allocations.

SOFTWARE

EPEDAT is a Windows^{TM} based software package, built inside MapInfo, which integrates several components: comprehensive fully integrated databases containing information on earthquake sources, buildings, lifelines, special facilities and population; geographic layers and associated databases containing information on known faults, historic earthquakes, maximum credible earthquakes, liquefaction susceptibility, county boundaries, city boundaries, zip code boundaries, census tract boundaries, and highways and major roadways; calculation engines that implement regional damage and loss models utilizing the extensive exposure databases to produce estimates of dollar losses and damage to buildings, including estimates of the number of red- and yellow- tagged buildings, estimation of casualties, and damage to lifelines, and; output of results in GIS and tabular format (results of calculations are available in text and map format).

Results include Modified Mercalli Intensity (MMI) maps which are automatically displayed in a MapInfo GIS format (Figure 2), and text files summarizing building damage estimates for cities and counties, as well as damage to lifelines. EPEDAT automatically prepares the geographic displays for multiple layer overlays (e.g. water transmission pipelines can easily be seen when overlain onto an MMI map). EPEDAT was designed to take advantage of information made available by CUBE. Accordingly, the only input information required for the user to generate earthquake loss estimates with EPEDAT is the preliminary epicentral location data (magnitude and lat/long coordinates) as broadcast over the CUBE pager system. (The user can also postulate earthquake scenarios without CUBE information, by modeling a historic earthquake, selecting a pre-determined Maximum Credible Earthquake, MCE, or locating a potential epicenter on-screen.)

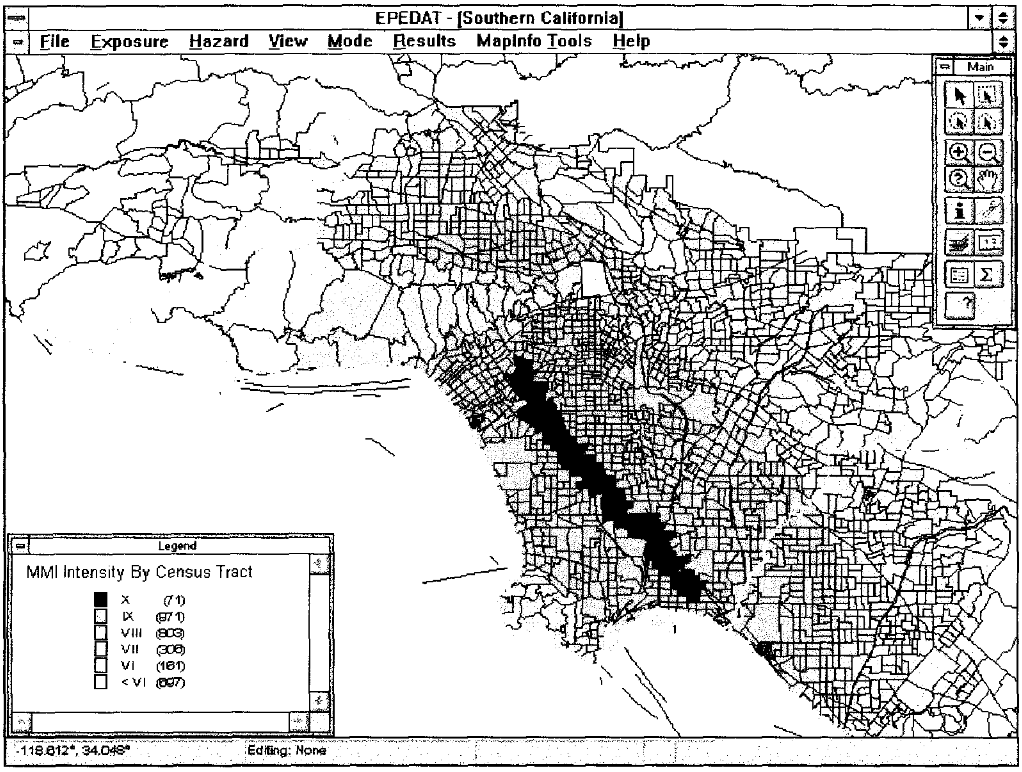


Figure 2. Sample census tract MMI map for a magnitude 7.0 earthquake on the northern Newport-Inglewood Fault. *In color:* front cover.

While the original intent was to have EPEDAT run automatically on a computer linked to a CUBE pager with no human intervention, program requirements and the realities of earthquake broadcast data (such as updates and aftershocks) have required a minimum of user intervention to determine the best CUBE data set for analysis. Accordingly, in the event of an earthquake, the EPEDAT operator would simply have to start up EPEDAT, enter CUBE mode at start-up, select the epicenter for use in the loss estimates, and then wait approximately 10 to 15 minutes (depending on computer speed) for the full set of EPEDAT loss estimates.

It should be noted that the CUBE mode is available only when EPEDAT is installed on a computer that also has the QPAGER software installed on it. However, the user can manually simulate a CUBE event by running a "user-input" event and entering the magnitude, latitude and longitude in the data entry screen.

APPLICATIONS

Perhaps it is appropriate to begin a discussion of applications or utilization with a conceptual discussion of "real-time" as it refers to seismic information. Originally a computer term, "real-time" pertained to a mode of computer operation in which data were collected, analyzed and applied to control a process as it happened (i.e., batch processing vs. continuous, or real-time, computing). The more general application of the term has become part of our technical jargon to refer to the retrieval and processing of information in a time frame in which it can be acted upon. With reference to earthquakes, real-time is usually linked conceptually and, in some cases, operationally, to monitoring systems which are capable of providing early warning or rapid post-event information (National Research Council, 1991).

For seismologists and engineers, real-time seismic information is data obtained and processed in a time frame extending from the initiation of an earthquake to the rapid broadcast of source data in the few minutes following the event. Real-time has a somewhat longer time frame for emergency managers for whom real-time means having critical information, whether observed or model generated loss estimates, in sufficient time for use in making mitigation and response decisions (Goltz, 1996a). These decisions, made in a time frame of minutes to several days, involve search and rescue, the need for medical resources, short and long-term sheltering, evacuations, lifeline and transportation impacts, damage assessment and securing and allocating federal disaster assistance funds. It is in this context that EPEDAT is a real-time decision support tool.

THE NORTHRIDGE EARTHQUAKE

Immediately following the January 17, 1994 Northridge Earthquake, data and models which were to become the basis for EPEDAT in Southern California were utilized and, though the system was not fully operational at the time, produced timely information which was used by state and federal officials to support key policy and program decisions. Estimates of dollar losses and ground shaking intensity were used by the California Office of Emergency Services to define the general regional scope of the disaster during the critical 24-48 hours after the event. The shaking intensity map was instrumental in approximating the locations of heaviest damage, used in briefing state agency executives, including the Governor, and in making decisions regarding shelter needs, locating Disaster Application Centers and "fast-tracking" the federal Disaster Housing Assistance Program. A total dollar loss estimate of $15 billion, generated within 24 hours of the earthquake, served as the basis for negotiation of a supplemental Congressional appropriation of $8.6 billion in federal disaster assistance.

A preliminary Modified Mercalli Intensity map using data and models from a GIS-based system which combines data on seismic sources, seismic activity, local geotechnical conditions and ground motion characteristics to estimate likely ground motion was delivered to OES at approximately 2:30 p.m. on Monday, January 17, 10 hours after the earthquake. A second shaking intensity map which was based on more complete data and prototype models being developed for emergency management decision support was prepared and presented to OES in digital form on January 21. (These maps are attached as Figures 3 and 4). These

MMI maps for the Northridge earthquake served three important functions for OES . The first map helped define the scope of the disaster in the hours of uncertainty following the earthquake. The second provided some guidance in early planning for recovery, and the basis for state and federal officials to "fast-track" the Federal Disaster Housing Assistance Program.

The Disaster Housing Assistance Program (Section 408A) is available to renters and homeowners to cover the cost of alternative housing if disaster-related damages render the primary dwelling uninhabitable. To qualify, an applicant must complete an application, indicate that the dwelling is not habitable due to earthquake damage and usually wait 2-5 weeks for an inspection to verify that the damage is severe enough to warrant an alternative housing arrangement. The maximum allowable amount of assistance is $3450 for a three-month period for homeowners and $2300 for a two-month period for renters. In the Northridge earthquake, the pre-grant inspection of the dwelling unit by a FEMA inspector was waived. Instead, the zip code of an applicant was matched with the estimated shaking intensity for that zip code; if the home was located in a mapped area corresponding to projected Modified Mercalli intensity of VIII, IX or X, the applicant was sent a check (there were 66 zip codes that were MMI VIII or greater). In this rather bold step, a total of 49,000 checks were sent amounting to $138 million in grants. Although some mistakes were made and reported in the media, verification inspections revealed that over 90% of those receiving checks were eligible based on established program criteria.

Perhaps the most important initial application of the total dollar loss estimates was in preparing the Preliminary Damage Assessment (PDA). Section 206.33 of the Stafford Act requires a preliminary damage assessment as part of the process which culminates in a Governor's request for a Presidential Disaster Declaration for an impacted area. This step in the federal disaster assistance process is critical for states in that it provides the basis for determining whether or not a situation warrants supplemental appropriations from Congress. Both the state and FEMA participate in preparation of the PDA which must contain an estimated dollar loss figure. Typically, this figure is a "back of the envelope" estimate based on a rapid survey of the damaged areas. The estimate of $15-17 billion dollars in total losses for the Northridge earthquake became the basis for the state's Presidential disaster request, although OES executives considered this estimate overly constraining and, after discussions with earth scientists and engineers who had done field reconnaissance, broadened the range to $15-30 billion.

On January 21, OES obtained estimates of nighttime casualties, including deaths and injuries, and an estimate of homeless caseload. These figures for Los Angeles and Ventura Counties were aggregated by city and county and expressed as broad ranges. The number of nighttime deaths was estimated at 40-430; nighttime injuries, 1,590-54,340; and displaced individuals, 6,490-19,400. The actual number of deaths was 57, the number of documented earthquake injuries, 11,846 and displaced persons, approximately 24,000.

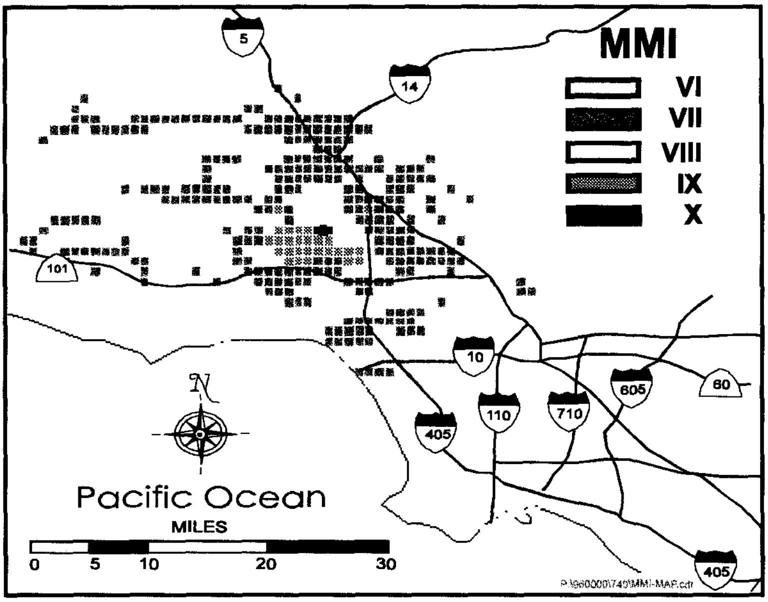


Figure 3. Preliminary estimates of Modified Mercalli Intensity for the Northridge, California earthquake of January 17, 1994. (Developed on January 17, 1994 using EQEHAZARD.) *In color:* see plates following p. 738.

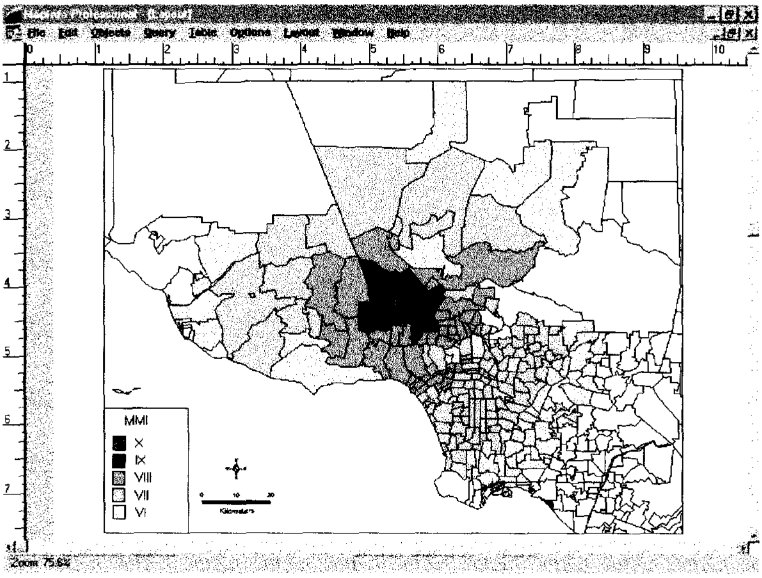
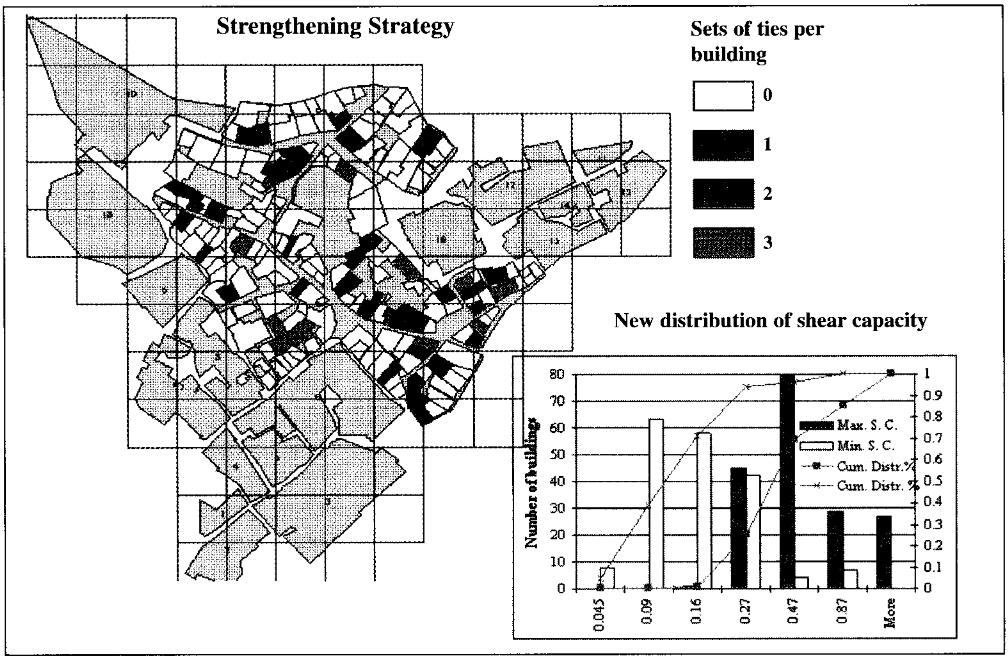
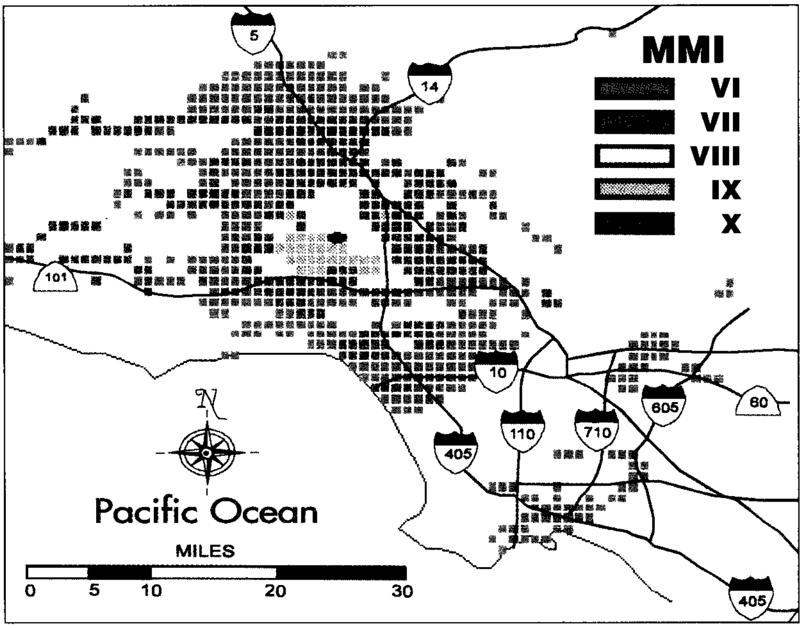


Figure 4. Estimated Modified Mercalli Intensities for the Northridge Earthquake based on models developed for the Early Post-Earthquake Damage Assessment Tool (EPEDAT). EQE International, Inc.



12) Map of the strengthening strategy and new shear capacity histogram. From D'Ayala et al., p. 787.



13) Preliminary estimates of Modified Mercalli Intensity for the Northridge, California earthquake of January 17, 1994. From Eguchi et al., p. 827.

Although estimates of deaths, injuries and displaced persons were not available in time to be useful to decision makers in the early response period, interviews conducted with key government officials after the earthquake (Goltz, 1996b) indicated that these estimates (delivered on the third day after the earthquake) served two important functions: 1) The estimate of displaced individuals helped confirm reports from the field that large numbers of people were out of their homes. Thus, the actual reconnaissance figures were more believable when compared to the projections generated by the model. 2) The exercise of estimating social impacts served to test the models employed in EPEDAT. The use of model estimates during the Northridge earthquake also appears to have enhanced user confidence in the application of loss estimation methods in real-time (Goltz, 1996b).

FUTURE APPLICATIONS

This section of the paper discusses other applications of EPEDAT beyond those previously identified for the Governor's Office of Emergency Services. In addition, the future benefits from a fully deployed TriNet program are also discussed.

Other Users

The current functioning EPEDAT system has a number of characteristics which were designed to meet the specific needs of a state level emergency operations organization. The databases, units of analysis, geographic scope and other features address the response and programmatic requirements of regional response to a damaging earthquake. In short, EPEDAT has been designed to assist the California Governor's Office of Emergency Services in making emergency response decisions for mutual aid, the disaster declaration process, damage assessment and the coordination of state level response.

The technologies which make up rapid loss estimation could, however, be applied in a number of planning and response environments. EPEDAT could be designed to meet the response needs of local government, lifeline organizations or large corporations with geographically distributed facilities and assets. These organizations might desire information on specific facilities requiring detailed databases in formats quite distinct from those which characterize EPEDAT in its present configuration. In addition, population, damage and loss data for a specific city or county would require greater detail and smaller units of analysis. Currently, EPEDAT provides estimates of shaking intensity at the zip code and census tract level and population on a census tract basis; local jurisdictions may need these data on a planning district, council district or even block by block basis.

In addition to different formats, other users may have distinct programmatic needs for rapid loss estimation systems. A utility district or transportation agency, for example, may require estimates of down time as well as the location and number of structural failures. Emergency response and recovery plan elements may be integrated into an EPEDAT system. Different types, levels and locations of damage could trigger pre-determined mobilization plans or recovery financing strategies. The point here is that the technology is versatile and the applications are many.

The TriNet Project

The TriNet project is a collaborative effort by the California Institute of Technology, the U. S. Geological Survey and the California Division of Mines and Geology to develop a digital seismographic network in southern California. This new network will provide ground motion data from three-component, high dynamic range, strong motion force balance accelerometers (FBA) with either real-time or dial up digital telemetry (Heaton, et. al., 1996). The major products of the TriNet project include: near real-time monitoring and cataloging of earthquakes in southern California; broad-band ground motions from teleseismic earthquakes and other sources; strong motion recordings from significant earthquakes in real-time; and, an earthquake early warning capability.

These products will contribute significantly to real-time loss estimation. Given EPEDAT's dependence on timely, accurate and reliable source data, the new digital network will produce improvements in all of these dimensions. The danger that large events will cause instruments to go off scale will be reduced significantly by the deployment of FBA's and digital telemetry will improve the timeliness of records. Even more significant is that real-time availability of strong ground motion measurements will greatly improve current intensity maps. EPEDAT currently produces estimates of regional shaking intensities and estimates of damage, losses and population impacts are based on these estimated intensities (in the form of contoured maps). TriNet will provide measured ground motions and actual intensities, not estimates, thus increasing the accuracy of parameters based on these measurements.

CONCLUSIONS

In the last several years, tremendous strides have been made to identify and expand the use of loss estimation methods for emergency management. While previous efforts to estimate losses have focused principally on pre-earthquake planning applications, new developments in real-time earthquake monitoring have made possible expanded and innovative applications of these methodologies. In this final section, we review how loss estimation methods have benefited from the Northridge earthquake experience and from the application of other related new technologies.

1. *Real-time loss estimation has strong potential to improve emergency response.* By having near real-time damage information on the earthquake, emergency response officials can prioritize response and recovery efforts to focus on those areas impacted most by the earthquake. Initial priorities can be established to coincide with areas of greatest shaking intensity or projected damage. In addition, damage projections can be used to estimate the level of resources required to support certain disaster assistance programs, e.g. temporary sheltering.
2. *The limited experience with loss estimates in the Northridge earthquake was positive.* The use of projected shaking intensities to expedite assistance to applicants for the federal Housing Disaster Housing Assistance program proved to be invaluable during the initial periods of the earthquake. Furthermore, the use of model produced loss projections, along with other field reconnaissance data, provided a more accurate and timely means of producing the Preliminary Damage Assessment (PDA) which is required for a formal Presidential Declaration of the disaster.
3. *The technology is flexible and can be applied in other regions and among a variety of potential users.* More areas throughout the U.S. are moving towards real-time earthquake monitoring

systems (e.g., Oregon - see Oregon Geology, Vol. 59, No. 5). Along with this movement will come the potential for better loss estimation tools. It is not unreasonable to expect that the same real-time loss estimation capabilities currently available in southern California will also be available in other areas of the country. Furthermore, the application of real-time damage assessment tools is not restricted to state and local government agencies only. Any organization with a need to quantify damage impacts immediately after moderate and large earthquakes can benefit from real-time earthquake monitoring and damage assessment tools.

4. *Rapid loss estimation can be integrated with other real-time information technologies to produce an integrated real-time emergency management support system.* Southern California provides an excellent model for how new technologies can be used and implemented to enhance emergency response capabilities and programs. New programs, such as early earthquake warning systems will also be initiated over the next several years in southern California. This experience should be transferred to other areas of the country.

ACKNOWLEDGMENTS

The work performed here was supported by the U.S. Geological Survey under contract number 1434-93-G-2306 and the California Governor's Office of Emergency Services (OES) under subaward number SC 320580. The support of these organizations in the development of this methodology is gratefully acknowledged. Specifically, the authors of this paper would like to thank the following individuals who helped to guide and advise the project team: Richard Andrews of OES; Carl E. Mortensen of the U.S. Geological Survey; Dave Kehrlein of OES; Professor Karen C. McNally of the University of California at Santa Cruz; Leval Lund, Consultant; and Kenneth W. Campbell and Charles R. Scawthorn of EQE International, Inc.

REFERENCES

Applied Technology Council (1985), "Earthquake Damage Evaluation Data for California," ATC-13.

Applied Technology Council (1996), "Earthquake Loss Evaluation Methodology and Databases for Utah," Prepared for the Federal Emergency Management Agency.

Algermissen, S.T., E.P. Arnold, K.V. Steinbrugger, M.G. Hopper and P.S. Powers (1988), "Earthquake Losses in Central Utah," U.S. Geological Survey Open-File Report 88-680.

California Division of Mines and Geology (1982a), "Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California," California Division of Mines and Geology, Special Publication 60.

California Division of Mines and Geology (1982b), "Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in the San Francisco Bay Area," California Division of Mines and Geology, Special Publication 61.

California Division of Mines and Geology (1987), "Earthquake Planning Scenario for a Magnitude 7.5 Earthquake on the Hayward Fault in the San Francisco Bay Area," California Division of Mines and Geology, Special Publication 78.

California Division of Mines and Geology (1988a), "Fault Rupture Zones in California," California Division of Mines and Geology, Special Publication 42.

California Division of Mines and Geology (1988b), "Earthquake Planning Scenario for a Major Earthquake on the Newport-Inglewood Fault Zone, California," California Division of Mines and Geology, Special Publication 99 (Preprint).

California Division of Mines and Geology (1990a), "Earthquake Planning Scenario for a Major Earthquake, San Diego-Tijuana Metropolitan Area," California Division of Mines and Geology, Special Publication 100.

California Division of Mines and Geology (1990b), Supplement No. 1 to Special Publication 42, California Division of Mines and Geology.

California Division of Mines and Geology (1994), "Fault-Rupture Hazard Zones in California," California Division of Mines and Geology, Special Publication 42, revised.

California Division of Mines and Geology (1995), "Earthquake Planning Scenario in Humboldt and Del Norte Counties, California for a Great Earthquake on the Cascadia Subduction Zone," California Division of Mines and Geology, Special Publication 115.

Central United States Earthquake Preparedness Project (CUSEPP) (1985), "An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from Earthquakes in the New Madrid Seismic Zone," Prepared for the Federal Emergency Management Agency (FEMA).

Central United States Earthquake Preparedness Project (CUSEPP) (1990), "Estimated Future Earthquake Losses for St. Louis City and County, Missouri," Prepared for the Federal Emergency Management Agency (FEMA).

Crippen, R.E (1992), "Measurement of Subresolution Terrain Displacements Using SPOT Panchormatic Imagery," Episode, Vol. 15, No. 1.

CUBE (1992), Cube Handbook: Third Draft, Caltech/U.S. Geological Survey Broadcast-of-Earthquakes.

Dames & Moore (1996), "Earthquake Loss Estimation Pilot Study for the Portland Metropolitan Region," Prepared for the National Institute of Building Sciences.

Eguchi, R.T., J.D. Goltz, H.A. Seligson, and T.H. Heaton, (1994), "Real-Time Earthquake Hazard Assessment in California: The Early Post-Earthquake Damage Assessment Tool and the Caltech-USGS Broadcast-of-Earthquakes," in *Proceedings of the Fifth U.S. National Conference on Earthquake Engineering*, Chicago, Illinois, July 10-14.

EQE International, Inc. (1997), "Second Pilot Test Study of the Standardized Nationally Applicable Loss Estimation Methodology, Boston, Massachusetts," Prepared for the National Institute of Building Sciences.

Goltz, J.D. (1996a), "Use of Loss Estimates by Government Agencies in the Northridge Earthquake," Earthquake Spectra, Vol. 12, Number 3, August.

Goltz, J.D. (1996b), "Use of Real-Time Seismic Information by Government Agencies, Utilities and Large Corporations in the Pre- and Post- Northridge Environments," Prepared by EQE International, Inc. for the National Science Foundation.

Hamada, M. and T.D. O'Rourke (1992), "Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes," Technical Report NCEER-92-0001, Vols. 1 and 2.

Harlan, M.R., and C. Lindbergh (1988), "An Earthquake Vulnerability Analysis of the Charleston, South Carolina Area," Department of Civil Engineering, The Citadel, Charleston, South Carolina.

Heaton, T.H., R. Clayton, J. Davis, E. Hawksson, L. Jones, H. Kanamori, J. Mori, R. Procella, and T. Shakal (1996), "The TriNet Project," Proceedings of the Eleventh World Conference on Earthquake Engineering, Acapulco, Mexico, June 23-26, 1996.

National Academy of Sciences (1989), "Estimating Losses from Future Earthquakes," Panel Report and Technical Background, FEMA Publication 176/177 (Earthquake Hazards Reduction Series No. 50/51), Panel on Earthquake Loss Estimation Methodology, Committee on Earthquake Engineering, Washington, D.C.

National Oceanic and Atmospheric Administration (1973), "A Study of Earthquake Losses in the Los Angeles, California Area," Prepared for the Federal Disaster Assistance Administration, Department of Housing and Urban Development.

National Research Council (1991), "Real-Time Earthquake Monitoring: Early Warning and Rapid Response," National Academy Press, Washington, D.C.

Priem, S. (1997), "Real-Time Earthquake Information," in Oregon Geology, Volume 59, Number 5.