Earthquake Loss Modeling Applications for Disaster Management: Lessons from the 1999 Turkey, Greece, and Taiwan Earthquakes

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Abstract

The field of catastrophe loss modeling has evolved tremendously in the past decade, largely driven by the needs and financial interests of the insurance industry. Earthquake risk models are now available for most of the world's most seismically-active regions where earthquake insurance premiums are sold. These models are usually embedded in software applications designed for insurance risk pricing and portfolio risk management. In the late 1990s, probabilistic (computer-based) methodologies for estimating potential earthquake losses were also ported into software applications for disaster management applications, such as response planning, post-disaster damage assessment, and reconstruction financing estimation.

Significant earthquakes in 1999 struck Turkey, Greece, and Taiwan, where earthquake loss modeling capabilities for the insurance and disaster management sectors varied significantly. Those differences provide an excellent opportunity for assessing the value, needs and future potential for these technologies. In each country, disaster managers had to undertake critical response tasks, such as identifying areas of concentrated damage, coordinating critical life-safety related response activities, such as search and rescue, and estimating short- and long-term housing and reconstruction financing needs. These were done with varying amounts of data, experience, and success. Lessons from these countries underscore the opportunities for improving existing disaster management technologies, and engaging in similar technology development activities in Europe and other regions of the world.

Introduction

The management of disaster-related risks is a means for evaluating, and hence "valuing" the potential consequences of catastrophic events. These consequences, and therefore risks, can be physical (such as damage to buildings), social (such as casualties and

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injuries), financial (such as the cost to repair damaged housing), and/or economic (such as the overall loss in gross product).

Loss estimation is a method for quantitatively valuing risk. Loss estimation approaches are generally rooted in science and require a tremendous amount of data and information in order to generate a valued result. Therefore, valuation tends to be less sensitive to judgment and parametric changes than more qualitative risk assessments.

But, in addition to predicting potential losses, the risk modeling applications and software that have been developed to date, have additional application and benefits in all phases of disaster management. Historic disaster data and science and engineering data collected for loss estimation are useful for analyzing hazards and vulnerabilities. The spatial and financial context of loss estimates is useful for mitigation, planning and prevention related tasks such as regulating land use, establishing building standards and community planning. Valuable information also aids in warning, response and recovery.

1999 Earthquakes: Quick Comparisons of Losses & Key Disaster Management Responses

In 1999, three damaging earthquakes struck countries where earthquake loss modeling capabilities for disaster management varied significantly. In each country, disaster managers had to undertake critical response tasks, and their use of modeling information in undertaking each task provides an opportunity to assess the value, needs and future potential for this type of technology.

Table 1, 2, and 3 provide quick comparisons of the various aspects of each event (EERI, 1999(2); Golan, 1999(2); Goltz, 1999; RMS, 1999; RMS, 2000; World Bank, 1999). They consider how each country handled some of the key initial response tasks of notification, response communication, and situation/early damage assessment, as well as how early recovery tasks of sheltering and damage/loss estimation were handled. Several sources of data were consulted for information on each earthquake. Since it has been less than a year since each event, all of these figures are still expected to change. Furthermore, in some cases, there were large differences in information provided by varying sources, and therefore some of the information presented is literally a “best guess” and potential ranges of values are offered.

Table 1. Key 1999 Earthquakes: Quick Comparison of Human Impacts

			Human Impacts		
Earthquake	Date/Local Time	Magnitude	Deaths	Injuries	Rescues
Kocaeli, Turkey	Aug. 17, 3:02AM	7.4	>18,000	>40,000	621
N. Athens, Greece	Sept. 7, 2:56 PM	5.9	143		86
Chi-Chi, Taiwan	Sept. 21, 1:47AM	7.6	2,405	10,718	>5,000

Table 2. Key 1999 Earthquakes: Quick Comparison of Financial Losses

			Losses (US$)	
Earthquake	Date/Local Time	Magnitude	Economic	Insured
Kocaeli, Turkey	Aug. 17, 3:02AM	7.4	$10 – 40 bil	$550 – 750 mil
N. Athens, Greece	Sept. 7, 2:56 PM	5.9	$600 mil - $4 bil	<$250 mil
Chi-Chi, Taiwan	Sept. 21, 1:47AM	7.6	$8 – 14 bil	$500 – 850 mil

Table 3. Key 1999 Earthquakes: Quick Comparison of EQ Monitoring & Modeling Status

Earthquake	Date/ Local Time	Magnitude	Seismic Network	Mapping	Notification/ Warning	Loss Modeling
Kocaeli, Turkey	Aug. 17, 3:02AM	7.4	Yes	Minimal	No	Minimal, no high-res
N. Athens, Greece	Sept. 7, 2:56 PM	5.9	Yes	Minimal	No	Minimal, no high-res
Chi-Chi, Taiwan	Sept. 21, 1:47AM	7.6	Yes	Yes	Yes	Taipei only

Table 4. Key 1999 Earthquakes: Quick Comparison of Key Government Response Decisions and Actions (Days After EQ)

Earthquake	Date/ Local Time	Magnitude	Local/Nat'l Response	Sheltering	Damage Assessment	Loss Estimates
Kocaeli, Turkey	Aug. 17, 3:02AM	7.4	1 – 4 days	> 7 days	7 days – 2 months	> 1 month
N. Athens, Greece	Sept. 7, 2:56 PM	5.9	1 – 2 days	1 – 7 days	2 – 14 days	> 7 days
Chi-Chi, Taiwan	Sept. 21, 1:47AM	7.6	< 1 day	1 – 7 days	1 – 30 days	> 1 month

M7.4 Kocaeli Earthquake: A Case Study in Post-Disaster Loss Estimation

The earthquake struck shortly after 3 a.m. local time on August 17, 1999, while residents of Turkey's Izmit Bay region were asleep. The earthquake's epicenter was near Istanbul and news media were quickly alerted. Early news information focused on the vast numbers of building collapses, search and rescue operations underway and the predicted heavy life losses. Fire ignitions were also featured, particularly the Tupras oil refinery fire. The towns surrounding Izmit Bay and the corridor leading to Istanbul are the heart of Turkey's industrial production.

Because of the enormity of loss, government response was overwhelmed. Search and rescue and initial response tasks were largely unorganized. Many of the earthquake's survivors were on their own for the first two days after the earthquake. National response was more fully engaged by the fourth day after the earthquake. Turkey's official damage survey and building tagging procedures were initiated, but both lacked resources to handle the magnitude of effort required.

About two dozen acceleration recordings were made of the Kocaeli earthquake, and five of these were within 20 kilometers of the North Anatolian fault. The majority of stations showed relatively low accelerations and only 2 stations recorded destructive intensities, limiting their utility for mapping the extent of important high intensity isoseismals. Turkey's seismic arrays did not have any real-time mapping capabilities.

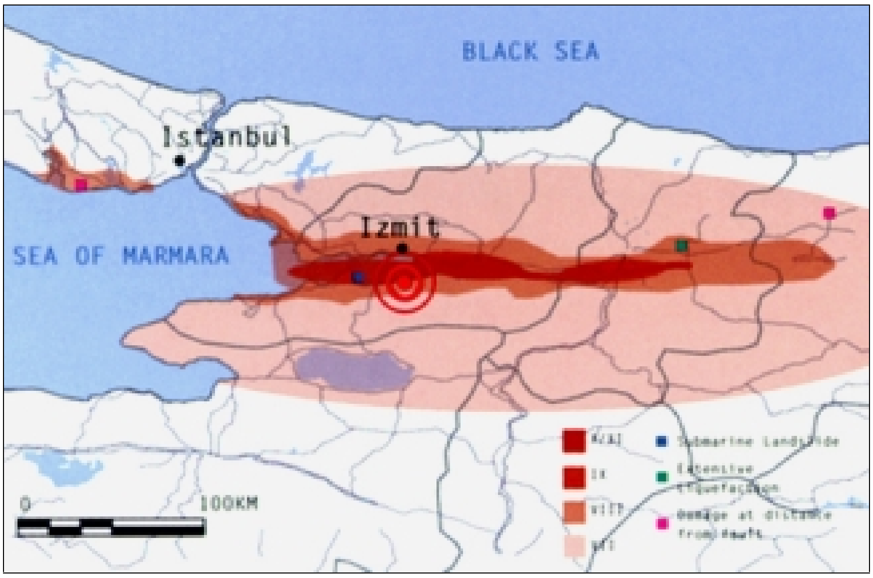
A regional, spatially-integrated view of the earthquake's impacts was initially lacking. Teams of national and international earthquake investigators converged in the first week of the disaster to collect valuable data and began defining more quantitatively the causes and impacts of the event. Investigators had coarse-resolution base map digital data loaded into laptop computers and hand-held GPS. Others relied on paper base maps and teams shared anecdotal information on field work each evening at the EERI reconnaissance team meetings. Several of the leading earthquake engineering and seismology laboratories in Turkey, including Kandilli Observatory at Bogazici University and the Middle East Technical University, worked hard to generate and publish information on the Internet as quickly as possible.

A quantitative technique for developing a shaking intensity map was used in Turkey to create a more quantitative understanding of the location and extent of losses and generate a loss estimate for the insurance industry. It relied on a rich data set of rapid, quantitative damage estimates in multiple locations, and assumed that at any location, affected by damaging ground motions, buildings would be found in a range of damage states. These damage states vary depending upon factors such as the type and quality of construction, age, building height and stories, soil and geological site conditions. This technique was originally developed using the damage scales and semi-quantitative intensity assessment techniques set out in the MSK Intensity Scale (Medvedev, Sponheuer, and Karnik, 1968). It has since been further developed into a more specific, quantitative scale, known as the European Macroseismic Intensity Scale (ECEE, 1998). Both of these scales are essentially comparable to the one more commonly used in the U.S., the Modified Mercalli Intensity (MMI) scale.

Using this technique, intensity assignments were determined by the quantitative damage distribution of statistically sampled, building types. More than 50% of the Kocaeli region's building stock is in heavy, poorly designed, non-ductile reinforced concrete construction. In the Kocaeli region, more than 50% of the building stock is in heavy, poorly designed, non-ductile reinforced concrete construction. More than 2,200 of these structures were surveyed.

The damage survey results were compared with the empirical damageability functions, or fragility curves, developed for non-engineered reinforced concrete frame buildings (based on global data (Coburn and Spence, 1992) to ensure that there was a good match. In some localized areas, the survey found that over 75% of these had been destroyed (RMS, 2000). The various damage distribution groups were then related to MMI values for expected damage and ground shaking levels. The locations of various MMI values were then mapped and compared for accuracy with the available strong motion recordings of the earthquake. Again, there was a relatively good match. It was now possible to display and estimate the land area affected by various levels of shaking (see Figure 1).

Figure 1. Preliminary Shaking Intensity Map, developed by Risk Management Solutions, Inc.



The average loss levels and the estimated numbers of insured risks in each MMI zone were determined and then combined to estimate insurance losses as US$900 million to $2.75 billion for direct losses and more than $500 million in potential business interruptions and other indirect losses (RMS, 2000). Although not probabilistic in the true sense, the analysis provided sufficient data so that a range of outcomes could be seen with different levels of possibility.

In the first two months after the disaster, 10,000 earthquake-related claims were filled with estimated damages of $750 million. The industry estimates hovered between $1.5 and $3.5 billion for several months; but, as of April 2000, the insurance industry has only paid about $500 million in claims, with an estimated $100 to 150 million left outstanding (Milli Re, 2000). Thus, the total insurance loss for the 1999 Kocaeli earthquake may be as high as $700 to $750 million. Of that total, about 70% is related to direct damage, and 30% due to business interruption losses. These figures are at the low end of the estimate generated based on the technique described.

M5.9 N. Athens, Greece EQ: A Case Study of A Post-Disaster Damage Survey

The earthquake struck during the afternoon of September 7, 1999, at approximately 2:56 p.m. local time, surprising the 4 million residents of Athens. Early information highlighted the uncertainty of the earthquake-generating fault's location. The most heavily damaged area was within a 12 km radius of the earthquake's epicenter, which was about 20 km from Athens' center. The earthquake caused extensive damage in the western suburbs of Athens, in an area that has been developed in the last 40 years. Over 100 buildings collapsed, with further damage to over 70,000 households and 8,000 businesses. Within the first day of the earthquake, the government initiated a sheltering process for 100,000 people rendered homeless by the earthquake. After two weeks of search and rescue operations under the rubble of collapsed reinforced concrete buildings, 86 people were rescued and 143 were confirmed dead (EERI, 1999).

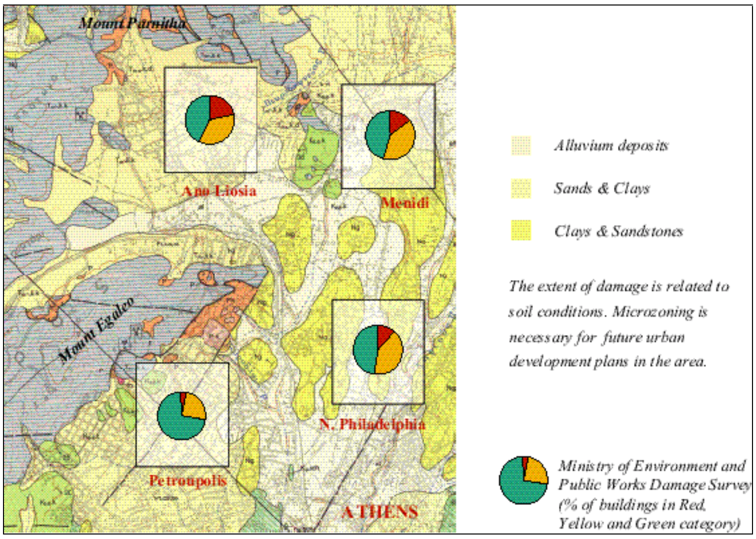
The proximity of this earthquake to the center of Athens shocked many Athenians who, though aware of earthquake risk in the area, did not realize that the region near Athens could generate such strong events. The event came only weeks after the devastating Kocaeli, Turkey earthquake, and aftershock fears were high among residents.

Although the earthquake was much smaller in magnitude than the Kocaeli and Chi-Chi earthquakes, the Greek's post-disaster recovery process deserves mention here. There were 14 strong motion recordings of the earthquake and the data were used by the national government for both damage assessment and loss estimation.

Prior to the earthquake, the national government had adopted and trained in damage assessment based on the ATC-20 rapid damage survey technique. Building tagging began on the second day of the earthquake, and 20 days after the earthquake, authorities completed initial inspections on about 185,000 buildings (RMS, 1999). Approximately 100 buildings collapsed, primarily low to mid-rise apartments and commercial/industrial buildings. Overall, 7% of inspected buildings had severe damage (13,000 buildings), and one-third of the surveyed buildings were classified with moderate damage (61,000 buildings).

Figure 2 shows a soils map used by the Greek Ministry of Public Works to map damages. While automated disaster management loss estimation and mapping tools were not available, the data collection process evolved quickly and was integrated with geologic and seismic data.

Figure 2. Soils Map used in Post-Earthquake Damage Distribution Mapping by the Minister of Public Works, Greece.



In the first week after the event, senior government officials put the cost of the earthquake at around 200 billion GRD ($600 million), but government officials realized that they had seriously underestimated the extent of the damage in the initial stages. Estimates were repeatedly revised as more information was collected from the damage surveys and integrated into the overall loss picture, By mid-November, the government had revised its total loss estimate upwards to 1.5 trillion GRD ($4.5 billion) (RMS, 1999).

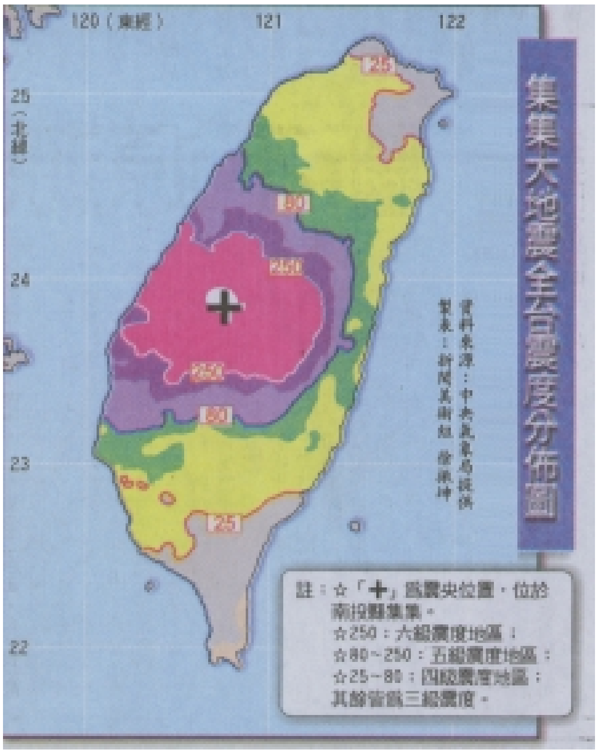
M7.6 Chi-Chi, Taiwan: A Case Study in Real-Time Mapping and Communications

The Chi-Chi earthquake struck the mountainous center of Taiwan during the night of September 21, 1999, at approximately 1:47 a.m. local time. Timing limited initial damage assessments and reporting. Early information focused on toppled buildings in Taipei, and the near island-wide power outage; but there was general uncertainty about the severity of impacts outside of Taipei city. As the days unfolded, more information emerged about damages throughout the epicentral region and there were reports of spectacular landslides and other ground deformations. As the power shortage continued, concerns about the potential impacts to the semi-conductor manufacturing sector began to emerge.

Real-time isoseismal mapping capabilities are now integrated into many of the seismic networks around the world; however, there are relatively few places where seismic networks have been installed at sufficient densities to provide accurate mapping of ground motion from recorded instruments (Eguchi, 1997). Taiwan is one of those few places. For nearly a decade, Taiwan’s Central Weather Bureau (CWB) has been building an extensive strong-motion instrument network across the island. At the time of the Chi-Chi earthquake, there were 600 strong-motion instruments in place across the island, with a real-time capability in 60 telemetered accelerometers. In little more than 2 minutes (102 seconds) after the earthquake, the event’s magnitude, location and strong motion data were communicated via pagers, fax, and the internet to the CWB and other key officials with response-related roles, including fire and police, nuclear plant managers, dam operators, and scientists.

A preliminary shaking map, based on instrument readings of peak ground acceleration, was generated within 2 minutes of the earthquake. This first version of the map lacked coverage in the central part of the island; however, an island-wide map of ground shaking levels was completed by the second day after the earthquake (see Figure 3). These preliminary shake maps appeared in newspapers and on television within the first few days after the earthquake. They were used by emergency managers and other officials in early post-earthquake response planning and decision making (Goltz, 1999).

Figure 3. Preliminary Shake Map (PGA) prepared by Taiwan's Central Weather Bureau, 1999.



Taiwan's response, particularly the early situation assessment, was triggered in large part by the rapid release of event parameters by the Central Weather Bureau. Since the earthquake was strongly felt in Taipei city, national government ministers were alerted by the actual shaking; many also received notification through pagers and other means.

National government ministers convened a meeting in Taipei within one hour after the earthquake (Goltz, 1999). Communications with local agencies were established within two hours after the earthquake. In general, local response was underway within hours. National-level response activities were underway by the end of the first day after the earthquake. Taiwan's armed forces were mobilized, and a national response priorities document was released within the first day. International search and rescue teams had organized assignments when they arrived. Local and national agencies began establishing shelters within the first day, and continued this task through the first week following the earthquake. The national government issued a six-month state of emergency decree on the fourth day after the earthquake. A damage assessment survey, based on the ATC-20 survey approach, was organized at the national level and tagging was undertaken island-wide.

A geographic information system (GIS) damage and loss assessment software application, called TaiHAZ, was under development at the time of the earthquake. TaiHAZ was capable of generating an island-wide Modified Mercalli Intensity map, but building, population and infrastructure data in the system covered Taipei city only.

Government officials began releasing building damage and loss estimates around two weeks after the event. These estimates were updated regularly for several months afterwards.

1999 Earthquakes: Lessons for Loss Estimation/Disaster Management

The 1999 earthquakes provide clear evidence for the usefulness of strong motion seismic networks in the provision of earthquake notifications and data for early response communications. Pre-disaster planning and training helped facilitate many response functions in Taiwan and Greece, including rescue operations, sheltering, and building/damage assessment. Linkages between strong motion networks and GIS-based damage assessment tools could help automate the process of spatial mapping, damage assessment and loss estimation post-event.

GIS-based damage assessment tools can provide a rich amount of quantitative data post-event that will enhance response & recovery efforts. Where such technology investments are being made, including the U.S., Japan, and Taiwan, efforts to link technology applications with post-disaster decision-making are also underway. One example of this is HAZUS™ - a GIS-based earthquake loss estimation tool created for local, state and regional public officials in the U.S. for planning, response, recovery and mitigation applications. RMS was lead developer of the original software and the earthquake methodology in this application. The National Institute of Building Sciences (NIBS) is managing the development of HAZUS™ under a Cooperative Agreement with the Federal Emergency Management Agency (FEMA). Similar technology applications are also currently under development for other perils in the U.S. and for other countries around the world, including Japan and Taiwan.

1999 Earthquakes: Future Needs & Opportunities for Risk Modeling

The 1999 earthquakes illustrate the needs for additional geologic, demographic, economic and structural data. GIS and database management applications need to be expanded, particularly in high-hazard areas. Policies and agreements are need to help standardize and to share data globally. Ideally, these agreements would be made in advance of catastrophes and there would be centralized data warehouse facilities and guidelines for integration. The procedures and tools for post-disaster applications of real-time risk/loss assessment are also needed. There are opportunities to enhance risk modeling as remote sensing technology and imagery become increasingly available, with special prospects in real-time risk modeling and ground truthing capabilities.

References

Coburn, A., and Spence, R., 1992. Earthquake Protection. J. Wiley & Sons: England, 355 pages.

Earthquake Engineering Research Institute (EERI),1999. The Chi-Chi, Taiwan Earthquake of September 21, 1999. Learning from Earthquakes, Special Earthquake Report, December 1999. Earthquake Engineering Research Institute: Oakland, CA.

Earthquake Engineering Research Institute (EERI),1999. The Athens, Greece Earthquake of September 7, 1999. Learning from Earthquakes, Special Earthquake Report, November 1999. Earthquake Engineering Research Institute: Oakland, CA.

Eguchi, R. et al., 1997. Real-Time Loss Estimation as an Emergency Response Decision Support System: The Early Post-Earthquake Damage Assessment Toll (EPEDAT). Earthquake Spectra, Volume 13, Number 4, November 1997. Earthquake Engineering Research Institute: Oakland, CA.

European Conference on Earthquake Engineering, 1998, 'European Macroseismic Intensity Scale', Appendix to the Proceedings of the 1998 European Conference on Earthquake Engineering.

Goltz, J., 1999, The "921" Chi-Chi, Taiwan Earthquake of September 21, 1999: Societal Impacts and Emergency Response. Based on Site Reconnaissance Conducted from September 28 to October 5, 1999. This Preliminary Report was Prepared November 10, 1999. Earthquake Engineering Research Institute (www.eeri.org).

Gulkan, P. et al., 1999, The 17 August 1999 Earthquake in Marmora Region, Turkey: Implications on Earthquake Engineering Research Needs and Priorities. Workshop on Research Needs Emerging from Recent Earthquakes. Workshop organized by the Earthquake Engineering Research Institute for the National Science Foundation, October 25 and 26, 1999.

Gulkan, P., 1999. Another Earthquake Occurs in Northwest Turkey. Information published on the Internet site of the Middle Easter Technical University.

Medvedev, S.V., Sponheuer, S., Karnik, V., 1968, 'The international scale of seismic intensity', in Seismic Zones of the USSR, Nauka, Moscow.

Milli Reinsurance, 2000. Based on information received in personal communications, April 2000. Milli Reinsurance: Istanbul, Turkey.

Risk Management Solutions (RMS), 1999. The North Athens Earthquake of September 7, 1999. Exposure: The Risk Management Solutions Magazine, Issue 5, Winter 1999. RMS: Menlo Park, CA.

Risk Management Solutions (RMS), 2000. Event Report: Kocaeli, Turkey Earthquake. RMS: Menlo Park, CA, 16 pages.

World Bank, 1999. Turkey: Marmara Earthquake Assessment. Dated September 14, 1999. The World Bank: Turkey Country Office.