ADVANCES IN NATURAL AND TECHNOLOGICAL HAZARDS RESEARCH

Robin Spence · Emily So · Charles Scawthorn
(Eds.)

Human Casualties in Earthquakes

Progress in Modelling and Mitigation

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Progress in Modelling and Mitigation

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Foreword

Natural disasters are one of the last remaining public safety issues for society to manage. Over the past centuries, the big killers of disease and accidents have gradually been tamed, and the causes of premature death are constantly being reduced by medical and technological advances.

In the modern world it should not be possible, or acceptable, for large numbers of people to die in the occurrence of geological processes like an earthquake, a volcanic eruption or a landslide. These are well understood phenomena and the science has existed for some time for us to understand their mechanisms, geography and temporal patterns. And yet sudden manifestations of these forces of nature continue to kill thousands of people, and in some cases tens of thousands and even hundreds of thousands of people, at a time.

The forces wreaked by nature are formidable, and yet there are ways that these forces can be understood, withstood, and accommodated. There are success stories where the infrastructure has been built strongly enough to withstand the energy unleashed on it, and the preparation has been sufficient to organise people to protect themselves when it has happened.

The protection of societies from these forces needs considerable forethought and planning. It needs a collective effort of will to recognise the threat, and to organise our social systems to meet this threat. We have to agree to invest in resilient infrastructure that has redundant capacity to withstand forces beyond those required for everyday needs. We have to divert resources to cope with exceptional requirements. We need a coordinated effort to build our buildings strong enough, and to provide planning resources to prepare for the severity of the extreme threats of nature.

And all this requires a political consent to invest in the safety standards required for social resilience.

But most importantly of all, we need to understand how casualties occur in these natural disasters. The underlying science needs to be firmly in place to show how best to prepare and to combat the destruction and social disruption that can ensue from geological events.

These collected papers are a welcome compilation of some of the groundbreaking science in understanding and combating casualties from natural hazards. They represent a wide range of studies in different countries, and different events and many different aspects of the causes of human death and injury.

The studies in this book provide a long-overdue re-examination by some of the world's leading practitioners in mass-casualty risk management. The contributors to this compendium have established a road map for the science, and set the challenge for society to follow to eliminate the risk of big death tolls from natural disasters in the years ahead.

Risk Management Solutions, Inc. Dr. Andrew Coburn

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Chapter 1
Introduction

R. Spence, E. So, and C. Scawthorn

1.1 Context

Earthquake and disaster casualties are a matter of serious political and humanitarian concern. At the time of preparing this book for publication, the world seems to be experiencing a rising tide of earthquake casualties. The death toll from the recent 12.1.2010 earthquake in Haiti is perhaps 220,000 killed with 500,000 injured. And this follows the major disasters of Wenchuan, China (88,289 dead), Yogyakarta, Indonesia (5,749 dead), and Kashmir, Pakistan (87,351 dead) all of which have occurred in the last 5 years. Just considering these events, the recent annual death toll has been more than 75,000, higher than in any comparable period in the last century. Figure 1.1 shows the decade by decade global fatality rate per million global population from 1900 until the end of 2009, putting the last decade into context.

Unfortunately, this rising trend of earthquake deaths is not a surprise: those who have examined the relationship between the earth's most active earthquake fault zones and their rising populations (Bilham 2009; Jackson 2006; Spence 2007) have, for some time, been warning that more major disasters, and larger ones, are inevitable. But it tragically demonstrates that we are very far from having an understanding of all the factors causing earthquakes to turn into major disasters, or of how to control these factors.

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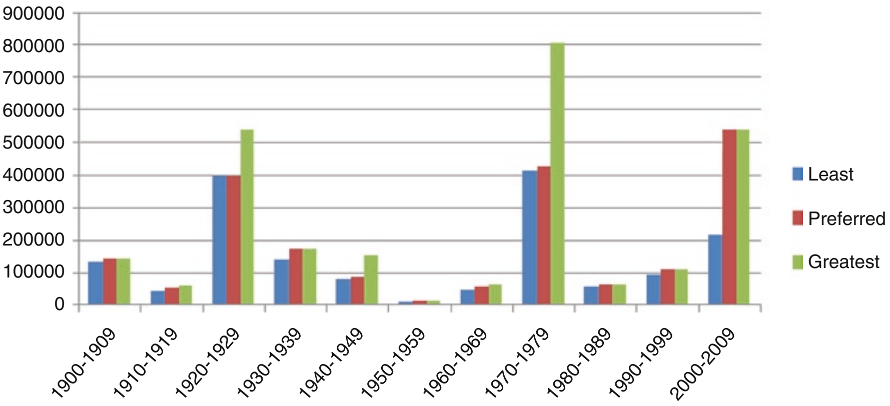

Fig. 1.1 Total earthquake deaths by decade since 1900. Only the 1970s in which 655,000 people may have died in the Tangshan earthquake had a higher death toll than the recently concluded decade. The least estimate generally does not include tsunami-related deaths (Source of data PAGER-CAT USGS)

Some of the broader causative factors are well known, and these have been again confirmed by recent earthquakes:

- *Poverty*: earthquake disasters causing large numbers of casualties almost always occur in relatively poor countries or regions – none of the ten events in the last 50 years with the largest death tolls occurred in a high-income country.
- *Building collapse*: the major primary cause of death in nearly every case (the 2004 tsunami being exceptional) was building collapse.
- *Construction method*: unreinforced masonry buildings remain the greatest danger to their occupants; but recent events have demonstrated that reinforced concrete buildings built without proper design or supervision can be as dangerous, and have the potential to bury and trap many survivors of the initial shock.
- *Collateral hazards*: even though the weakness of buildings under ground shaking is the greatest cause of death, other possible causes such as landslides and tsunamis, may in some cases be of great importance.
- *Response*: slowness of search, rescue and treatment resulting from the absence or incapacitation of emergency services, can greatly increase the final death toll.

But from each of the recent major disasters, new lessons have been learnt on the causes and nature of death and injury, as well as on the factors contributing to unusually high death tolls. Examining some recent events where additional casualty studies have been carried out, factors which have had a major impact on the final casualty number are shown in Table 1.1.

The table highlights particular key factors contributing to deaths that must be considered in casualty modelling. However, data on the precise causes of death and injury are in most cases not available. Given that additional work has been carried out by researchers on this list of events, there are even less data on other events.

Table 1.1 Important lessons learnt from 10 recent events

Event	Date (local time)	Important lessons
Northridge, Mw 6.7	17 January, 1994, 04:30	*Few fatalities due to time of day*: What if the earthquake had occurred during rush hour? Portions of Interstate 10 (the Santa Monica Freeway), Interstate 5 (the Golden State Freeway) and State Route 14 (the Antelope Valley Freeway) all collapsed and had to be rebuilt, casualties could have been generated should these have been carrying traffic.
Kobe (Great Hanshin), Mw 6.9	17 January, 1995, 05:46	*Time of day*: Many killed at home in building collapses but, if earthquake had been an hour later, Shinkansen bullet train and many other trains would have all derailed. Review of old vulnerable timber housing leading to wake-up call for Japanese earthquake design.
Kocaeli, Mw 7.4	17 August, 1999, 03:02	*Building quality*: Building control called into question in Turkey.
Athens, Mw 5.9	7 September, 1999, 14:56	*Response*: Transportation networks were operational and enabled immediate rescue of people trapped in 35 out of the 50 totally and partially collapsed buildings
Chi Chi, Mw 7.6	21 September, 1999, 01:47	*Time of day*: Collapses of a series of high-rise and public buildings; deaths tolls could have increased if during working hours.
Bhuj, Mw 7.7	26 January, 2001, 08:46	*Building quality*: Extremely weak rubble masonry housing suffered the most but site effects were also significant.
Bam, Mw 6.6	26 December, 2003, 05:26	*Building quality*: Low-strength masonry buildings virtually all collapsed; this combined with close building spacing hampered escape and access for search and rescue.
Kashmir, Mw 7.6	8 October, 2005, 08:50	*Building quality*: Heavy concrete flat roofs on rubble stone masonry created few void spaces for survival. Widespread landslides and poor access to remote areas.
Yogyakarta, Mw 6.4	27 May, 2006, 05:53	*Building quality*: The evasive action of many during this earthquake helped in reducing the number of fatalities compared to the of number collapsed buildings in this area.
Wenchuan, Mw 7.9	12 May, 2008, 14:28	*Building quality*: Landslides and mudslides contributed to already failed or failing buildings. The high population density in these remote towns and villages was unexpected.

1.2 Motivation and Aims of the Book

It is evident that there are many aspects of earthquake casualties which remain unclear or uncertain, and this has resulted in an absence of reliable earthquake casualty models. Earthquake risk and impact modelling is growing in importance; it can contribute to the development of appropriate building regulations and controls for urban development; it is essential for the planning of post-event emergency operations; and it contributes to the development of insurance schemes and to the planning of mitigation measures in the existing building stock. But for all of these purposes, it is vital to be able to estimate the number of deaths and the number and type of injuries which may result from a given pattern of earthquake ground shaking.

Making such estimates requires a more detailed understanding of the causative factors of earthquake deaths and injuries than is currently available. Some of the currently undetermined questions are

- What are the precise nature and detailed causes of injuries and deaths in recent earthquakes?
- What is the quantitative lethality of different types of buildings, and what is the relationship between levels of building damage and injury?
- What ratios of deaths and seriously injured to overall affected populations can be expected in different circumstances?
- To what extent is the time of day of the earthquake occurrence a factor?
- To what extent do deaths and injuries have structural and non-structural causes?
- How do injury and death rates differ according to the behaviour of individuals in response the ground shaking?
- What other factors contribute either to survival or to exceptionally high casualty rates?
- How effective has search and rescue been in finding and rescuing trapped survivors?
- How effective has emergency medicine been in identifying and treating earthquake injuries?
- Can death rates be reduced by affordable improvements in building methods; or by better public awareness training; or by better communication of public warning following precursory events?

A series of International Workshops on Disaster Casualties has in recent years been established in order to promote further investigation of these questions. Two such workshops have been held, the first in Kyoto in November 2007 and the second in Cambridge in June 2009 at which a number of papers were presented, with participation from researchers and practitioners from Japan, Europe, the United States and elsewhere, and including engineers, architects, health professionals and emergency managers. The proceedings of these two workshops form the basis of this book.
With this background, the purposes of this book are

1. To present the most important new evidence produced in the two workshops, in order to summarise current trends in the understanding of the factors influencing the numbers and types of casualties in disasters

2. To offer methods to incorporate this understanding in the estimation of losses in future events in different parts of the world, and
3. To discuss ways in which pre-event mitigation activity and post-event emergency management can reduce the toll of casualties in future events

The book thus constitutes both a gathering of the evidence on these research questions, and a presentation and evaluation of the results of some of today's earthquake casualty models.

1.3 Scope of the Book

The book is organised into four sections according to the main topic of each chapter, although there is inevitably some overlap of subject matter between the sections. *Part I: A Global Perspective*, assembles four papers which look at data and information on earthquake and disaster casualties generally, and discuss different approaches to the analysis of that data. Chapter 2 examines the data on casualties which has been assembled in the EM-DAT database at CRED, Louvain; Chapter 3 constitutes a comprehensive review of existing research on casualties and public education; Chapter 4 discusses how to define in economic terms, the impacts of injuries and deaths in natural disasters, and introduces the concept of Economically Adjusted Life Years (EALY). It also considers the evidence for a diurnal variation in the pattern of earthquake deaths, and concludes that such a variation is detectable in the data. Chapter 5 presents an overview of the casualty components of the Cambridge University Earthquake Damage Database (CUEDD), now the Cambridge Earthquake Impact Database (CEQID) which assembles building damage data from more than 50 worldwide earthquakes, comprising over 1.5 million affected buildings, and shows the results of some analysis of the assembled data in relation to ground shaking and building types.

Part II: Casualty Loss Modelling comprises four chapters describing existing casualty models, and presenting the results of some applications of these models. Chapter 6 presents the development of casualty models for use in the USGS PAGER (Prompt Assessment of Global Earthquakes for Response) system which is widely used to support emergency response and relief efforts, and discusses the global data sources on which they are based, describing the empirical, semi-empirical and analytical approaches they use for making casualty estimates. Chapter 7 presents the loss estimation tool QLARM being developed by the World Agency of Planetary Monitoring and Earthquake Risk Reduction (WAPMERR), also designed to be used for immediate post-earthquake emergency and relief planning, and discusses how its components are calibrated on the basis of past events worldwide. Chapter 8 describes the Extremum loss estimation system developed by the Seismological Centre of the Russian Academy of Sciences, which is also designed for immediate post-earthquake response, and is strongly based on losses experienced in the former Soviet Union countries. Its rapid post-event estimates are compared with the actual reported data for several recent events. Chapter 9 describes the various casualty models which were used to estimate injuries and deaths that might occur in the M7.8 "Shakeout" scenario in Southern California.

The five chapters in *Part III: Lessons Learnt from Regional Studies* present significant new data and observations derived from studies relating to particular countries or regions. Chapter 10 presents some of the earthquake casualty data assembled by the Russian Centre for Disaster Medicine, which forms a basis for the casualty estimates of the Extremum system, and for the planning of post-event medical support of the affected populations in the Russian Federation. Chapter 11 discusses the seismic vulnerability of buildings in Greece using data prepared to support the development of the PAGER system; the experience of casualties associated with building collapse in Greece is summarised, and presented alongside decadal global earthquake fatality data from 1900. Chapter 12 presents a model for the rapid estimation of casualties in Italy, and its application to the 2009 L'Aquila earthquake. The results of the model run conducted in the first few hours after the event are presented and are shown to have a surprisingly good agreement with the eventually recorded numbers of deaths, injured and homeless. Chapter 13 constitutes a detailed examination of the deaths and injuries which occurred in the L'Aquila earthquake, in which 305 people died, and 1,500 were injured. The geographic and demographic distribution of deaths and injuries are examined, and their relationships to patterns of collapse associated with the characteristic building types of the region are investigated, leading to some conclusions on survivability in conditions of building failure. Chapter 14 presents the results of an extensive questionnaire survey conducted in Ojiya City, Japan, following the 2004 mid-Niigata earthquake. 4,400 household surveys were collected, making this by far the largest survey of its kind ever conducted. The nature and causes of injuries were investigated, and relationships between the injury type, location, cause and occupant behaviour are traced.

Part IV: Exploring Approaches to Improved Casualty Modelling brings together a set of six chapters presenting research on a variety of ways to improve casualty modelling, through acquisition and analysis of field data, laboratory studies and social surveys. Chapter 15 presents the approach to casualty modelling which underlies the development of the PAGER system, and therefore complements Chapter 6. It looks at the sources of data for the hazard, exposure and vulnerability components of the PAGER model, and points to other ways in which these datasets have been and might be used to improve casualty estimation, and to better understand the uncertainties in existing models. Chapter 16 discusses the problems of acquiring injury and fatality data from the field following an earthquake. It describes in detail a questionnaire which has been developed and used to capture the experiences of survivors in three separate events: Kashmir, Pakistan in 2005; Yogyakarta, Indonesia in 2006; and Pisco, Peru in 2007. Issues of questionnaire design, sampling, survey management and ethics are discussed.

Also within Part IV, Chapter 17 introduces some general issues concerning the estimation of numbers of deaths and injuries in earthquake models. Given the significance of damage level, it is suggested that a new damage level ($D5^+$ meaning complete collapse) should be introduced. Using evidence from earthquakes in Portugal and the 2009 L'Aquila earthquake, the importance of accurate data on resident population and on the possible behaviour in response to precursory phenomena and warnings is emphasised. Chapter 18 discusses the injury/fatality ratio R in earthquakes. It is shown that R has increased with time, and that it is very different in the industrialised and developing world. It is suggested that the improvement in R implies a general improvement of the quality of the building stock globally. It is proposed that values of R specific to different building classes be used for the estimation of casualties in earthquake loss models.

Laboratory investigation of building performance in earthquakes is a well-established field; but for human casualty investigation, it is still in its infancy, with the first steps being taken in Japan. Chapter 19 examines how the impact of earthquakes on the human body can be systematically investigated. It describes the development, at Osaka City University, of an instrumented mannequin and its laboratory testing, for use in large scale shaking-table tests. It also describes the development of a "cyber-mannequin" suitable for applications to finite element simulations of the collapse of structures. With these tools a new field of research into the direct causes of human injuries in earthquakes is facilitated, making possible fresh insights into opportunities for mitigation. Chapter 20 deals with an alternative, social science, approach to understanding human vulnerability. It presents the results of a social survey of risk perceptions. Using stratified samples of the population in three earthquake risk cities (Seattle, Osaka and Izmir), the degree of perception of earthquake risk, and the extent to which individuals had taken measures to protect themselves from earthquake loss (seismic adjustments), were investigated. Surprisingly it is found that there is only a weak correlation between seismic risk perception and seismic adjustment activity.

Several good papers presented at the workshops were unable to be published in this book either for reasons of space, or because they were destined to be (or have already been) published elsewhere. From Japan, Professor Aiko Furukawa presented a paper which showed how computer simulation of the performance of buildings in earthquakes can be carried out using discrete event simulation (DES) techniques, and how the results of such simulations can be used for estimation of the casualty potential resulting from partial and total collapse of small masonry buildings (Furukawa et al. 2009). Captain Larry Collins of the Los Angeles Fire Department described the activities of the Fire Department during the 2008 Shakeout Southern California earthquake simulation exercise (Chapter 9), and lessons learnt from the experience. This has been published in the journal Fire Engineering (Collins 2009).

In other papers presented at the workshops but not published here, Mary Lou Zoback and colleagues from Risk Management Solutions described an important project to address the humanitarian impacts of futures earthquakes on six of the most at-risk South American Cities; Tomoko Shigaki and Michio Miyano from Osaka City University presented an investigation of the call-out records of the Osaka City Emergency Department over the period 1990–2005, arguing that the areas of greatest intensity of everyday emergency are likely also to be the areas most impacted by major disasters. Peter Baxter of Cambridge University's Institute of Public Health presented an overview of human casualties in volcanic eruptions; Nabil Achour of Loughborough University presented a discussion of the issues involved in the planning of hospitals to face a major influx of casualties in a post-disaster situation; Professor Yutaka Ohta from Japan's Tono Institute presented an overview of earthquake-related research from the medical literature using the PubMed database; and Akiko Yoshimura from the Earthquake Disaster Mitigation Centre (EDM) in Hyogo Province, Japan described the design and implementation of Japan's first full-time training centre for Urban Search and Rescue. Although they are not presented here, summary presentations and slides on these topics may be found on the website of the Cambridge University Centre for Risk in the Built Environment (www.arct.cam.ac.uk/curbe).

1.4 Research Needs

An aim of the two International Disaster Casualties workshops was to set an agenda for future research in three separate areas

- Empirical casualty loss modelling
- Development of mechanical and behavioural models
- Emergency management

Consequently, a session at each workshop was devoted to this aim. Short-term and more long-term research goals were distinguished, as indicated in the following paragraphs.

For loss modelling, it was agreed that essential short-term goals would include the creation of a database of all existing empirical data on casualties in past earthquakes, with tools for cross-event analysis, and to develop common protocols and standards for collecting data, including an agreed taxonomy. This implied the need for close collaboration among disciplines, and involvement with the World Health Organisation. In the longer term, research is needed to understand the correlation of casualties with physical observations of the causative factor, to understand the uncertainties, and to improve casualty estimation models, making use of the data collected in the proposed database. Better understanding of the global building stock, and making use of advanced remote sensing techniques, will be an essential background for such studies. Further development is also needed of methods for incorporating earthquake-related disability into economic calculations of the costs of earthquakes, in order to strengthen the economic case for mitigation actions.

For the development of mechanical and behavioural models, new modelling and simulation techniques such as discrete element modelling (DEM) for building performance and smoothed particle hydrodynamics (SPH) for modelling of tsunami-building interaction were recognised to have great potential; a much greater range of different types of structure need to be investigated, exploring newly available enhancements in computing power. Eventually it is anticipated that the interaction between buildings and occupants and their behaviour could also be explored by such models. But calibration of such models against real observations, both of building performance and individual behaviour, either in the laboratory or in the field, was agreed to be vital to give such models credibility. This area of research has great potential for the longer term.

For emergency management, key short-term research goals were to find ways to collect data about what leads to survival in earthquakes, including the activity of SAR (search and rescue) teams. The need for better international collaboration among SAR agencies was stressed. A longer term goal would be to create and analyse a database of SAR activities in a range of events to understand the role of spatial constraints, building typologies, arrival delay and SAR team composition on SAR effectiveness. At a national level, it was agreed that much can be done in many cases to improve communication between governments and the population about how to behave before, during and after an earthquake, offering an important field for social research.

Potential users of such research were identified as national emergency management agencies, health planners, urban authorities, building standards regulators, as well as business and private individual owners and occupants of buildings. Research objectives for each user community would be somewhat different subsets of the overall research agenda. The planned research activities of the GEM (Global Earthquake Model) risk and socio-economic impact components will be an opportunity for many of these shorter- and longer-term research needs to be addressed, and the workshops addressed prioritisation of GEM's research agenda.

As engineers and scientists, we know that though the events themselves are unavoidable, the consequences and the deaths from earthquakes can be mitigated. Recent earthquakes have been the motivation behind this book which focuses on understanding, modelling and documenting. Only by such efforts can we gain confidence in improving global loss modelling, disaster preparedness and mitigation in the future.

Part I
A Global Perspective

Chapter 2
Earthquakes, an Epidemiological Perspective on Patterns and Trends

D. Guha-Sapir and F. Vos

Abstract The unpredictable nature of earthquakes and the vast impact they can have makes them one of the most lethal kinds of natural disaster. Earthquakes have claimed an average of 27,000 lives a year since 1990, according to the data on reported deaths compiled by the EM-DAT International Disaster Database, which is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University in Louvain, Belgium. The consequences of earthquake disasters vary around the globe, depending on the region and its economic development. Data shows that the number of earthquakes causing significant human and economic loss has increased since the 1970s, endorsing research into individual risk patterns which can provide important information for community-based preparedness programmes. Epidemiological analysis of earthquake impact data can be useful for evaluating impact patterns over space and time. However, the lack of standard definitions of exposure to risk of death or injury from earthquakes is an ongoing methodological obstacle and contributes to inaccuracies in calculations of rates and ratios for comparison purposes. Standardised definitions of deaths and injuries from disasters would improve understanding of earthquake-related risks.

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2.1 Introduction

Earthquakes can have devastating impacts in a matter of seconds. Their unpredictable nature and the potential scale of their impact make them one of the most lethal of all disasters, claiming an average of 27,000 lives a year worldwide since the 1990s. If we look at the science behind the death tolls, earthquakes are caused by faulting, a sudden lateral or vertical movement of rock along a rupture surface. Accumulated strain in the earth along faults is released, resulting in radiation of seismic energy and ground shaking. Earthquakes can also be triggered by volcanic or magmatic activity or other sudden stress changes in the earth (Stein and Wysession 2003; Bolt 1988). There are more than 1.4 million earthquakes a year around the planet, an average of almost 4,000 per day.[1] And yet, of course, if earthquake phenomena occur in uninhabited areas where they do not have any human impact, they remain hazards rather than disasters. If, on the other hand, they strike urban areas with high population density or communities where buildings are not earthquake-resistant, there is the potential for major disasters with large-scale human loss, especially in the case of larger earthquakes.

Scientists and researchers have increasingly focused their attention beyond seismology and the physics of the earth's structure and interior, to look at real-time earthquake damage estimation. It is possible to estimate the seismic hazard or how much an earthquake could potentially shake the ground in an area by looking at local seismicity and seismotectonics and from records of strong-motion accelerographs (Berckhemer 2002). Computer simulations and experimental designs have been used to investigate the dynamic response of technical construction elements. Seismic building codes provide a basis for recommending earthquake-resistant construction. Much has been written on this (Kanamori and Brodsky 2001; Chen and Scawthorn 2002; Bullen and Bolt 1985; Coburn and Spence 2002; Aki and Richards 2002; Scholz 2002; Lay and Wallace 1995). However, in this paper we focus on the human impact of disasters. As a result, we restrict our discussion to analysis of relevant earthquake statistics in the EM-DAT International Disaster Database maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain in Belgium.

The aims of this paper are to display and analyse the global data on earthquakes held by CRED's EM-DAT database, the reference source for systematic global disaster data, from an epidemiological perspective. Following this introduction, Section 2.2 provides an overview of the methodological parameters that guide the way natural disasters are recorded in EM-DAT. It will also discuss the challenges thrown up by potential ambiguities in disaster data collection. This is followed in Section 2.3 by a description of global patterns and trends in earthquake occurrence and their human impact. Finally, in Section 2.4 we will offer some conclusions and suggestions for future research in this area.

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[1] http://earthquake.usgs.gov/learn/faq/?faqID=69, accessed on 1 December 2009.

2.2 Recording Natural Disasters in EM-DAT

In this section, we will describe the methodological procedures and parameters used in the CRED EM-DAT International Disaster Database, which is a unique public source of information used by a wide variety of scientists, policy makers and operational organisations.[2] We will also outline some of the methodological challenges encountered in disaster data collection.

2.2.1 EM-DAT: Objectives and Methodology

CRED provides standardised data on disaster occurrence and loss around the world.[3] Its wider goal is to contribute to information dissemination for disaster management in order to enhance regional, national and local capacity to prepare for, respond to, and mitigate disaster events. CRED has maintained EM-DAT since 1988 with the initial support of the U.N. World Health Organisation (WHO), the U.N. Disaster Relief Organisation (UNDRO) and the Belgian government, and since 1999 with the sponsorship of the Office of Foreign Disaster Assistance at the United States Agency for International Development (OFDA-USAID). The main objectives of the database are to:

- Assist humanitarian action at both national and international levels
- Rationalise decision-making for disaster preparedness
- Provide an objective basis for vulnerability assessment and priority-setting

Historical disaster data can help to determine the characteristics of disaster risks and analyse trends in them. EM-DAT contains essential core data on the occurrence and impact of more than 18,000 natural and technological disasters around the world from 1900 to the present. The database is compiled from various sources,[4] including U.N. agencies, governmental and non-governmental organisations, insurance companies, research institutes and press agencies. The data inserted in EM-DAT

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[2] See also: www.emdat.be

[3] See also: www.cred.be

[4] This includes U.N. bodies (Food and Agriculture Organisation – FAO, Integrated Regional Information Networks – IRIN, Office for the Coordination of Humanitarian Affairs – OCHA, U.N. Environment Programme – UNEP, World Food Programme – WFP, WHO, World Meteorological Organisation – WMO, Economic Commission for Latin America and the Caribbean – ECLAC), U.S. governmental bodies (Centers for Disease Control – CDC , Federal Emergency Management Agency – FEMA, National Oceanic and Atmospheric Administration – NOAA, OFDA, Smithsonian Institution), official agencies (Asian Disaster Risk Reduction Center – ADRC, Caribbean Disaster Emergency Response Agency – CDERA, national governments), NGOs and humanitarian organisations (International Federation of Red Cross and Red Crescent Societies – IFRC), reinsurance companies and magazines (Lloyd's Casualty Week, MünichRe, SwissRe), inter-governmental organisations (World Bank), press agencies (AFP, Reuters), and other specialist sources (Dartmouth Flood Observatory – DFO, U.S. Geological Survey – USGS). This is not an exhaustive list.

follows a strict methodology using standardised definitions, and the validation procedure is intensive. Validated data are uploaded to the EM-DAT website at three-month intervals, and economic loss data are cross-checked and completed with data from MünichRe NatCat[5] and SwissRe Sigma databases.[6]

For the purposes of EM-DAT, a disaster is defined as: "a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering". For a disaster to be entered into EM-DAT, it must fulfil at least one of the following criteria:

- Ten or more people reported killed
- 100 or more people reported affected
- A declaration of a state of emergency
- A call for international assistance

Each EM-DAT disaster entry conforms to a set of fields that is uniform throughout the database (Table 2.1).

Table 2.1 Overview of main parameters included in EM-DAT

Field name	Content of field
DISNO	Eight-digit disaster ID composed of year + sequential number (e.g. 2009-0037)
Country	Country of disaster occurrence
Disaster group	Natural/technological disasters
Disaster sub-group	Geophysical, meteorological, hydrological, climatological or biological disasters
Disaster type and sub-type	Description of the disaster according to a pre-defined classification
Date	Start/end date of disaster
No. people killed	Persons confirmed as dead and persons missing and presumed dead
No. people injured	People suffering from physical injuries, trauma or an illness requiring medical treatment as a direct result of a disaster
No. people homeless	People needing immediate assistance for shelter
No. people affected	People requiring immediate assistance during a period of emergency, including displaced or evacuated people
Total no. affected	Sum of injured, homeless and affected people
No. victims	Sum of killed and total affected people
Estimated damage	Estimated economic damage in US$ × 1,000 (reported values)
Geographical information	Location, latitude and longitude
Additional fields	E.g. scale/magnitude of disaster, international status, aid contribution, affected sectors

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[5] See also: www.munichre.com/en/ts/geo_risks/natcatservice/default.aspx

[6] See also: www.swissre.com

2.2.2 Finding the Right Definitions and Terminology

One of the major challenges in the field of disaster data today is finding a way to overcome the limitations that result from not having standardised definitions. The lack of universal definitions leads to inconsistencies in reported disaster figures and makes it extremely hard to compare and exchange data between multiple disaster data compilation initiatives. In response to this, CRED and MünichRe have recently led a collaborative initiative on a Disaster Category Classification for Operational Databases in order to come up with standardised terminology for global and regional databases on natural disasters (Below et al. 2009). This initiative is an important step towards standardising disaster databases worldwide, which should help to improve the quality and interoperability of disaster data.

2.2.3 Challenges in Disaster Data Collection

All global datasets have inherent limitations on their data, and this is certainly the case for global disaster data sets. Information sources reporting data on disasters have different objectives, so data may not be gathered and communicated specifically for statistical purposes. This means that the quality of disaster statistics depends to a large extent on the reporting sources. There are ambiguities in the definitions and criteria used to describe the human impact of disasters. Up until now, there has not been any commonly applied definition of ‘people affected by a disaster’. The numbers reported for disaster-related deaths sometimes include the missing, but sometimes do not, so if the reporting is not clear it is easy for mortality figures to be inflated or deflated.

Likewise, economic losses are often loosely reported or even missing altogether, because of the complexity of assessing damages. In EM-DAT, economic loss data are cross-checked with other specialist sources, such as reinsurance companies. While no database can capture complete information on all events, the statistics compiled in EM-DAT provide an insight into trends which can be used to appreciate the direction and comparative impact of different disasters. On a positive note, consensus has been reached in recent years on definitions and thresholds in reporting disaster statistics, which makes global data more consistent and easier to compare.

2.3 Global Patterns and Trends in Earthquake Occurrence and Human Impact

Earthquake disasters are distributed through time and over space with a wide range of potential consequences. First, we will look at the trends in natural disasters that we can identify in the EM-DAT database from 1900 until the present day. After this, we will draw on the improved quality of data reporting and better coverage of global events to do further analysis of earthquake disasters between the first day of 1970 and the end of 2008. We will only include disasters that meet the EM-DAT criteria as described in Section 2.2.1.

2.3.1 Long-Terms Trends in Natural Disasters

EM-DAT has a record of more than 11,000 natural disasters dating back to 1900. Of these recorded events, 85% took place since 1970. One of the main factors contributing to this apparent increase in natural disasters is improved reporting, influenced by the launch of OFDA-USAID in 1964 and CRED in 1973.

The data represented in Fig. 2.1 might lead one to believe that disasters occur more frequently today than in earlier decades. However, it would be wrong to reach such a conclusion based solely on this graph. When interpreting disaster data, one has to take into account the inherent complexity of disaster occurrence and human vulnerabilities, as well as how statistics are reported and registered. Furthermore, developments in telecommunications and media, increased humanitarian funding and improved international cooperation have all contributed to better reporting of disasters, particularly the smaller-scale ones.

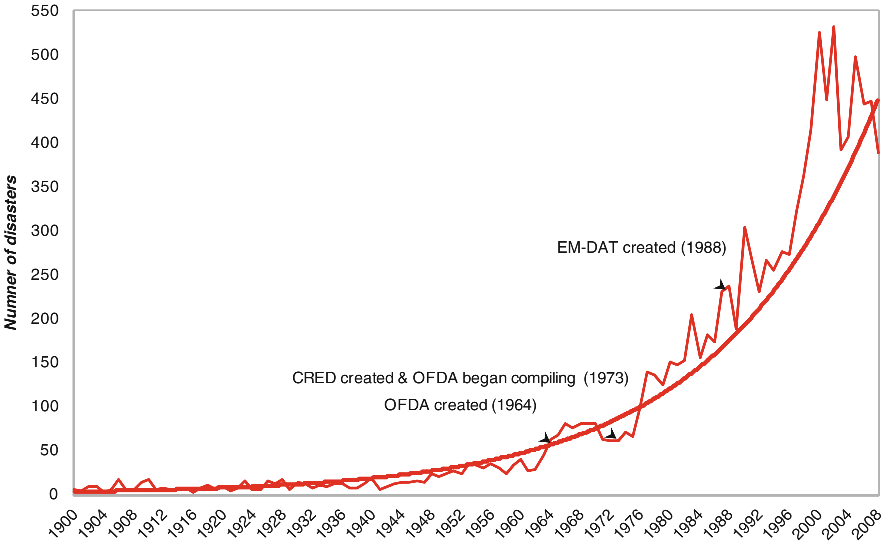


Fig. 2.1 Reported natural disaster occurrence in EM-DAT (1900–2008)

2.3.2 Earthquake Disasters: Patterns and Trends from 1970 to 2008

In recent decades, data quality and coverage have vastly improved. Media coverage of global events has expanded widely, and telecommunication costs have decreased. The increased use of internet and email correspondence has also improved the timeliness and quality of disaster reporting. In this section we look at some patterns and trends in the earthquake data since 1970.

An annual average of 21 earthquake disasters has been reported over the last 39 years, according to EM-DAT criteria (see Section 2.2.1). But over the last 9 years, this average has increased to 30 earthquakes per year. Figure 2.2 shows the frequency of seismic shocks with significant human impact. The three peak years for high numbers of earthquake disasters were 1990, 2003 and 2004. In 1990, both Asia and Europe experienced frequent seismic activity with significant human consequences. In that calendar year, 13 earthquakes – ranging from 5.8 to 7.7 on the Richter scale of magnitude – hit Asia, and 12 earthquakes occurred in Europe with magnitudes ranging from 4.7 to 6.8 on the Richter scale. The rest of the world also experienced several major earthquakes. By far the most lethal earthquake in 1990 was the earthquake which hit Iran on June 21 with a magnitude of 7.3 on the Richter scale. It struck Manjil-Rudbar at 00:30 local time, killing 40,000 people and affecting more than 700,000 others. In the same year, a 7.7-magnitude earthquake struck the densely populated island of Luzon in the Philippines on July 16, killing 2,400 people and affecting more than 1.5 million others.

In 2003, 29 earthquakes occurred in Asia, of which 11 were in China and five in Iran. The destructive 6.6-magnitude Bam earthquake, which struck Iran on December 26, 2003 at 05:26 local time, killed 27,000 people and affected 270,000 others.

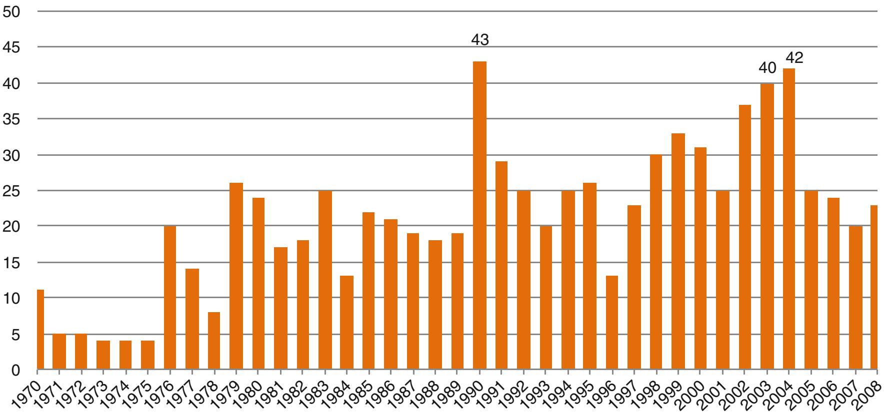


Fig. 2.2 Number of earthquakes with human impact according to EM-DAT criteria (1970–2008) (Tsunamis included)

Fig. 2.3 Earthquake occurrence (%) by continent 1970–2008

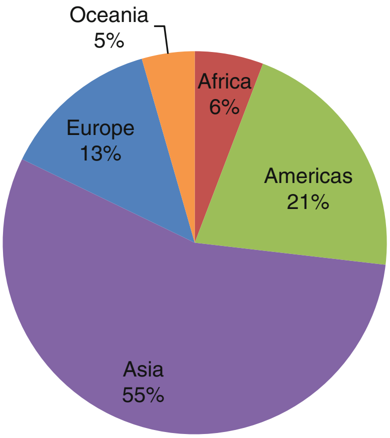
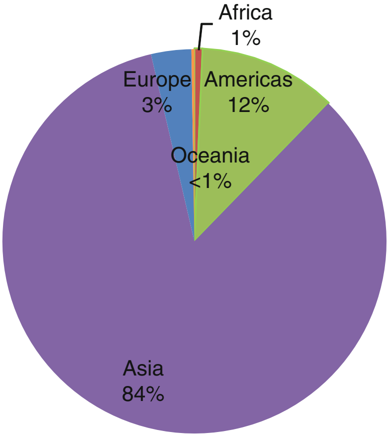


Fig. 2.4 Earthquake fatalities per continent (%) 1970–2008



A 6.0-magnitude earthquake struck the Yunnan province of China on July 21, 2003 at 23:16 local time, affecting over 1.3 million people.

Asia was struck again by a series of earthquakes in 2004. In that year, Indonesia (six) and China (five) were the two countries with the highest individual contribution to the continent's total of 26 earthquakes. On the other hand, a single massive event, the devastating Sumatra-Andaman earthquake and tsunami of December 26, affected 12 countries, increasing the annual total of human disaster earthquakes in the region. It killed more than 226,400 people, with a total of 2.4 million affected, and inflicted damage costing US$10 billion.

Profiles of earthquake occurrence and their impact differ between continents (Figs. 2.3–2.6). During the past 39 years, Asia is the continent with the highest number of earthquakes (with an average of 55% of each year's share), followed by the Americas (21%). When we look at the human impact, over 80% of earthquake victims are in Asia. Damage costs from earthquakes are also highest in Asia, partly due to the high frequency of earthquakes in relatively wealthy Japan and the widespread scope of damage in India. Despite relatively low earthquake numbers,

Fig. 2.5 Earthquake victims per continent (%) 1970–2008

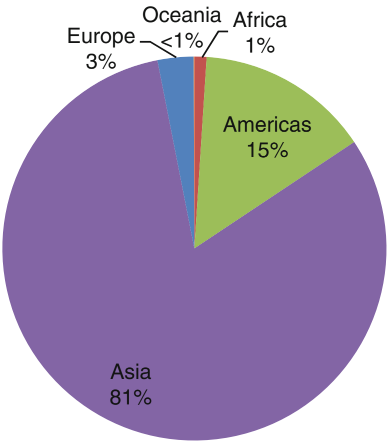
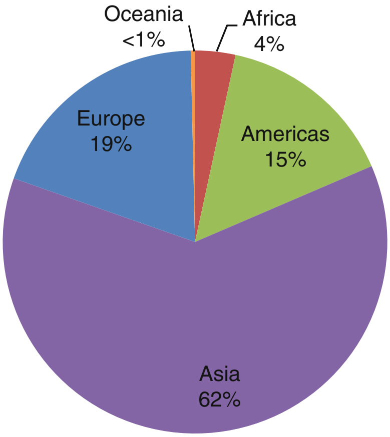


Fig. 2.6 Earthquake damage costs (%) by continent 1970–2008



Europe accounts for nearly 20% of damage costs, compared to the Americas – another relatively high-income region – which remain at 15%.

Finally, if we look at how the share of victims has changed over time, Asia's burden has increased substantially in recent decades, as shown in Fig. 2.7. The two peaks in this figure represent the 1988 earthquake which hit India and Nepal at a magnitude of 7.0 on the Richter scale, with over 20 million victims, and the 2008 Sichuan earthquake in China (magnitude 7.9), which claimed more than 46 million victims. Victims, according to EM-DAT terminology, include both the dead and affected.

If we rank individual countries by the number of earthquakes that occurred in them over the last 39 years, China tops the list, experiencing a total of 99 earthquakes that had major human impact. Indonesia comes second, with 80 earthquakes during this same period. Although China and Indonesia are relatively big countries, a larger surface area is not necessarily associated with a higher frequency of disastrous earthquakes. Other larger countries, such as Brazil, Russia or India, do not experience more earthquakes due to their size, since earthquake occurrence is not randomly distributed across the globe. Table 2.2, which compiles the top ten countries

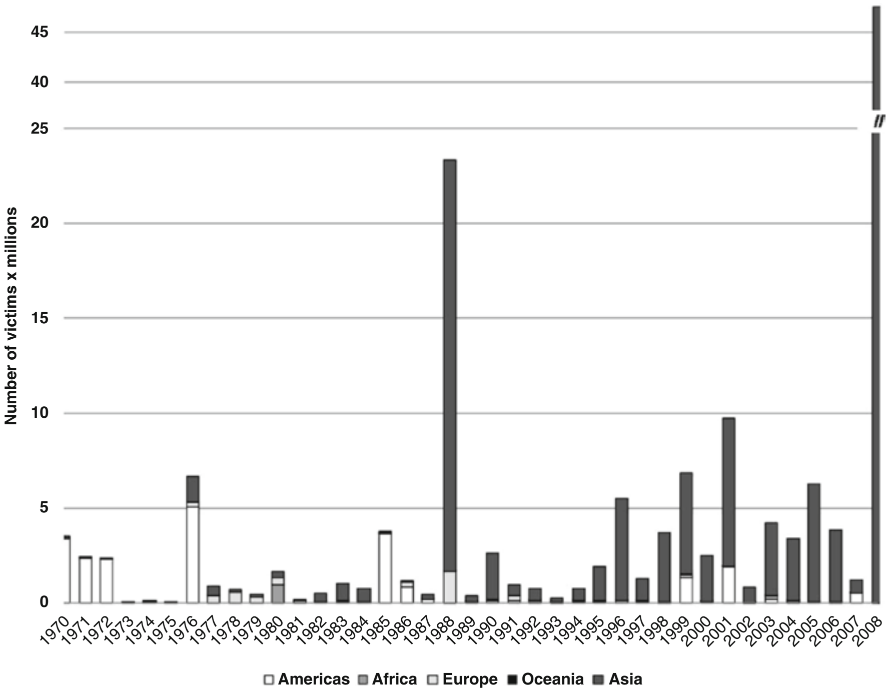


Fig. 2.7 Trend in number of earthquake victims per continent 1970–2008

Table 2.2 Top ten countries with highest number of earthquakes 1970–2008

Country	No. earthquakes
China	99
Indonesia	80
Iran	74
Turkey	42
Japan	34
Peru	27
Afghanistan	25
United States	24
Italy	23
Greece, Mexico	22

with the highest number of earthquakes, highlights countries located in high-risk geographical locations, such as the Pacific's Ring of Fire.

If we look at the ten most fatal earthquakes of the last 39 years, low- and middle income countries top the list (Table 2.3). When earthquakes strike, the human impact can be enormous, killing hundreds of thousands of people in a few seconds. Earthquake risk increases with population growth and urbanisation, as well as with poverty. Low-quality building construction and inadequate spatial planning put people in danger, and we often find that earthquake damage is particularly destructive

Table 2.3 Top ten most destructive earthquakes in terms of human impact (1970–2008)

Date	Country	Richter	Killed (× 1,000)	Total affected (× 1,000)
27 Jul 1976	China	7.8	242	164
26 Dec 2004	Indian Ocean tsunami[a]	9.0	226	2,432
12 May 2008	China	7.9	88	45,977
08 Oct 2005	Pakistan, India, Afghanistan[b]	7.6	75	5,285
31 May 1970	Peru	7.8	67	3,216
21 Jun 1990	Iran	7.3	40	710
26 Dec 2003	Iran	6.6	27	268
07 Dec 1988	Armenia	6.9	25	1,642
16 Sep 1978	Iran	7.7	25	40
04 Feb 1976	Guatemala	7.5	23	4,993

[a] Affected countries: Bangladesh (two killed, zero affected), India (16,400 killed, 654,500 affected), Indonesia (165,700 killed, 532,900 affected), Kenya (one killed, zero affected), Malaysia (80 killed, 5,100 affected), Maldives (102 killed, 27,200 affected), Myanmar (71 killed, 15,700 affected), Seychelles (three killed, 4,800 affected), Somalia (298 killed, 105,100 affected), Sri Lanka (35,400 killed, 1,019,300 affected), Tanzania (ten killed, zero affected), Thailand (8,300 killed, 67,000 affected)

[b] Pakistan (73,300 killed, 5,128,000 affected), India (1,309 killed, 156,600 affected), Afghanistan (one killed, zero affected)

in countries with developing economies. Poor people are most vulnerable, being forced to settle on steep hillsides, flood-prone alluvial land, low elevation coastal zones and valleys at risk of landslides, or to develop their livelihoods around terraced agriculture. However, the extent to which each of these factors play a role is not yet well understood.

The ratio of people killed (mortality) to injured (morbidity) by earthquakes can provide information that is useful for planning the type and amount of supplies and personnel needed in a disaster relief effort (Lechat 1979). Earlier research has estimated a ratio of one person killed for every three people injured by earthquakes measuring 6.5–7.4 in magnitude on the Richter scale (Alexander 1985; De Ville de Goyet et al. 1976). The magnitude of the earthquake is one of several determinants of the consequent mortality or morbidity. Many factors in addition to earthquake severity influence the human consequences. These include the time of the day the event occurred, distance from the epicentre, secondary events triggered by the earthquake, urbanisation grade, building standards and regulations, and access to medical care, as well as social and behavioural customs (Ramirez and Peek-Asa 2005; Chou et al. 2004; Liang et al. 2001; Armenian et al. 1992). Unravelling which of these factors played the predominant role in determining the level of loss is complicated without extensive data on the affected community both before and after the event. Even more fundamentally, methodological problems faced in comparative analysis of earthquake morbidity and mortality are the lack of standardised concepts and definitions for the number of ‘injured’ and ‘affected’ people. Furthermore, estimating the size of the population at risk is challenging due to poor census data and movement of citizens and relief personnel from and towards the disaster site. Under- or overestimation of the number of earthquake-related injuries and deaths influences the determination of the magnitude of the health impact in the population. The relationship between causal factors and their outcomes is difficult to determine, since information on risk factors and injury data are incomplete and often completely lacking. On a positive note, in the recent years, the importance of reliable data is increasingly recognised and there are efforts to improve organised surveillance of injuries and collection of data at medical treatment sites. Useful analyses from the Sichuan earthquake in 2008 as well as the Kashmir earthquake in 2005 based on field data are being published (Zhang et al. 2009; Wen et al. 2009; Xie et al. 2008; Mulvey et al. 2008), contributing to the evidence base on risk factors for human impact of earthquakes.

2.4 Conclusions

Annually, since 1970, numbers of earthquakes with major impact on human populations have increased. Increasing population growth in zones of high seismic risk or decreasing quality of physical structures may transform a less significant quake to a major disaster. For example, Asia faces an increasing number of earthquake events and associated victims and structural losses. The extent to which this vulnerability is due to population pressures, unbridled urbanisation and inadequate housing requires special study. Globally, risk factors that expose a population to loss of life or major injuries remain inadequately understood whereas, without this knowledge, it is difficult to put in place an effective preparedness or prevention plan.

Long experience with the EM-DAT international disaster database has convinced us that standardised definitions for human impact indicators – such as people injured or people affected – would be a significant step forward in improving understanding of earthquake-related risk. Key concepts such as definitions, even conventional, that describe the population exposed to death and injury from earthquakes have yet to be established. As a result, not only are results from different studies not comparable, denominators are inadequate even within a study, making rates and ratios suspect.

It is now widely recognised that the distribution of deaths and injuries caused by earthquakes varies greatly according to the region and the economic development of the community in which it occurs. However, individual risk patterns can reveal information that could contribute to improving community-based earthquake preparedness programmes. Statistical analysis of earthquake impact data can be useful for evaluating impact patterns over space and time. Besides, well-designed case-control studies and, more ideally, cohort studies could significantly contribute to generating evidence on risk factors for earthquake mortality and morbidity.

Acknowledgments The authors would like to thank Olivier Degomme and José Rodriguez-Llanes (CRED) for their contribution to data analysis, and Laura Irvine (CRED) for her contribution to proofreading of the text.

Chapter 3
Earthquake Casualties Research and Public Education

M. Petal

Abstract The mitigation of deaths and injuries is of primary concern to all disaster prevention efforts. It is to the specific causes of deaths and injuries that we must look for fundamental guidance in disaster risk reduction and public education. Disaster epidemiology provides the important evidence basis for identifying and prioritising effective structural and non-structural mitigation and environmental protection measures to be taken at all levels of society, as well as for planning for disaster response and for behavioural guidance during and after onset. Epidemiological data found in the literature is compared for individual, built environment, hazard, mitigation, and response level variables. This evidence lends important credibility to several key recommendations to the public in the areas of structural and non-structural safety, response skills and provisions. Finally, community-based training for disaster response is strongly indicated by the evidence that 'the people around us' are the true first responders.

3.1 Earthquake Epidemiology

It is now widely understood that for disaster mitigation efforts to be effective they must take place at all levels of social organisation, from the individual and family (at the micro level) to schools, workplaces, organisations, agencies, neighbourhoods and local government (at the meso level) and wider government and policy-making institutions (at the macro level).

While the recurring devastation caused by earthquakes on the built environment of human inhabitants has called forth vast research on the shaking of the earth and on the seismic-resilience of buildings, alarmingly little has been learned about the causes of deaths and injuries. Of the ten deadliest earthquakes of the past 35 years

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Table 3.1 The ten most recent deadliest earthquakes (from PAGER-CAT 2008)

Year	Country	Estimated fatalities	Year	Country	Estimated fatalities
1976	China	242,219	2001	India	20,023
1978	Iran	18,220	2003	Iran	26,271
1989	Armenia	25,000	2004	Indian Ocean	228,000 (incl. tsunami)
1990	Iran	45,000	2005	Pakistan	87,351
1999	Turkey	17,439	2008	China	69,195

(Table 3.1), published scientific studies of the causes of deaths and injuries are available for only Armenia and Turkey.

Post-hoc extrapolations from the varying official and unofficial estimates of deaths and building damage have primarily yielded the general finding that ‘earthquakes don’t cause deaths, buildings do’. This has occasioned a significant body of valuable research on buildings. However, much less is known about the specific causes of both injuries and deaths and how to avoid them. This has left us with an unfortunate disconnect between advice for disaster mitigation and preparedness dispensed in the name of “public awareness”, and the evidence-basis for this guidance.

Earthquake epidemiology “the study of the distribution of death and injury in earthquakes and the causes of fatal or nonfatal injury” (Jones et al. 1994), was born with the 1976 analytic study of the Guatemala earthquake (Glass et al. 1977). This was the same year that a public health leader made fervent argument to the international health community that it was important to adopt a wide perspective on the cultural aspects of disaster and the potential for disaster epidemiology to guide mitigation and to recommend looking at deaths and morbidity across time (Lechat 1976).

In the ensuing decade, in the face of sparse data on the causes of deaths and injuries, engineering-based casualty-modelling and estimation emerged for the purpose of providing a rational basis for planning relief, and response (Noji 1997b; Seligson et al. 2002). More than a dozen estimates of the vulnerability of Californians to various scenario earthquakes emanated from the National Oceanic and Atmospheric Administration, the U. S. Geological Survey, the Federal Emergency Management Agency, and the Division of Mines and Geology. The worst prognosis was FEMA’s 1980 calculation that a rupture of the Newport-Inglewood fault in Southern California would result in approximately 23,000 deaths and 91,000 injuries (Aroni 1990).

The early studies of risk factors for earthquake injuries found in the engineering literature did not employ epidemiological methods at all, and from the perspective of social scientists and health professionals did not accurately or reliably assess risks (Jones et al. 1993). Commenting on the prediction for Southern California, Aroni and Durkin state:

> In spite of the potential of buildings for injury and disruption, surprisingly little is known about (1) how people are actually injured (2) what elements or building types are particularly hazardous, (3) how people behave during and immediately after an earthquake to avoid or induce injury (4) what effects such as health status, age and prior training have on injury, and (5) what can be done to mitigate particular dangers. … more research is needed on the particular aspects of buildings that have actually caused injury in past earthquakes. (Aroni and Durkin 1985)

Indeed they recognised that:

> …because of the dearth of empirical data, potentially misleading ‘conventional wisdom’ about how to avoid injury in earthquakes has accumulated. This ‘conventional wisdom,’ based on overly general assumptions of building performance in earthquakes and on the capability of occupants to perform recommended actions, needs urgent reappraisal. For example, although doorways occasionally survived the collapse of un-reinforced masonry buildings, the recommendation to stand in a doorway is not sufficiently specific for type of building or type of doorway to be particularly useful to occupants. (Aroni and Durkin 1985)

In the 1980s, in order to refine our understanding of some of these variables, FEMA sponsored an Applied Technology Council (ATC) study to develop Modified Mercalli Intensity-based damage functions related to 70 standardised structures and 35 occupancy categories (ATC 1985). ATC-13 was used to provide injury and death rates related to each building classification. In the absence of more refined data, a 4:1 ratio of serious injuries to deaths, in buildings damaged beyond repair, became the rule of thumb.

When the “Ad Hoc Working Group on Earthquake Related Casualties” met in 1989 (USGS 1990) the three earth scientists contributed the geophysical and geological factors at work: earthquake source parameters, attenuation of seismic waves, site response, ground failure and wave/inundation. The six engineers focused on the definition of lethality (number of fatalities/number of collapsed buildings) and life-safety ratios (number of fatalities per 10,000) and ratio goals in relationship to building class. Those from architecture and urban planning looked at optimisation of search and rescue response (Krimgold 1990) and planning education, and policy issues (Aroni 1990). The lone sociologist and public health physician contributed concerns about the epidemiology of injuries following building collapse (Tierney 1990) and concerns about field data collection post earthquake, medical response effectiveness, injury patterns, association between types of lesions and types of building materials, and quantitative injury severity scores (Noji 1990b). Tierney noted that “If over the years there had been even one-tenth the number of persons working on the problem of earthquake casualties as were working on building effects, real progress might have been made on casualty estimation” (Tierney 1990).

Offering leadership in research on the relationship between building damage and casualties, The Martin Centre for Architectural and Urban Studies used a relatively straightforward quantitative model with parameters of: (1) occupancy of building class by function (2) occupancy by time of day and season (3) lethality of collapse of different construction types and (4) search and rescue effectiveness (Pomonis et al. 1991). Research pointed to the increasing implication of reinforced concrete structures in earthquake casualties, especially taller buildings, and high occupancy buildings (as adobe and stone construction was waning with urbanisation). They made an important observation that since anti-seismic building codes assume that buildings will not collapse, the issue of occupancy has been given short shrift despite there being many regions around the world where anti-seismic design and construction codes either don’t exist or are not enforced. Also, neglected are taller RC buildings at risk from long-period seismic waves even from distant earthquakes. And, they penned the now ubiquitous refrain: “Although evidence from past earthquakes has shown that “L” or “U” shaped buildings are more vulnerable, or that soft storeys and short columns are significantly increasing the vulnerability of the building, in most earthquake countries the lessons have yet to be passed on to the construction industry." (Pomonis et al. 1992)

In 1985 one team looked at a series of vulnerability strata (e.g. historical influence on the physical environment, buildings at risk, density, risk perception, and economic risk) to try to understand the cause of 5,000 deaths in Mexico City (Durkin 1989). Subsequent studies, mostly in California, began to try to decipher variables across human (personal characteristics: age, sex, state of health), physical (local and regional seismicity and all factors in the built environment including nonstructural elements and building contents), socio-economic (institutional and cultural factors including social roles), and circumstantial (date and time of the event) factors in relationship to the phases of the hazard cycle (Aroni 1990).

In the 1990s GIS began to be applied to estimation of damage and economic losses to building inventories. The HAZUS methodology (NIBS and FEMA 2003) expresses damage estimates in terms of probability of a building being in one of four damage states: slight, moderate, extensive and complete. Injury severity is also categorised into four levels: (1) requiring basic medical care without hospitalisation, (2) requiring greater medical care and hospitalisation, but not life-threatening, (3) immediately life threatening if not treated adequately and expeditiously (4) instantly killed or mortally wounded. The model relies upon indirect estimates of the characteristics of the earthquake itself (magnitude, intensity, location), inventories of building stock, occupancy states and estimates of lifeline performance. However, in the absence of data on deaths and injuries, HAZUS could not provide for much variation in casualty rates across building types.

More recently, the EPEDAT (Early Post-Earthquake Damage Assessment Tool) methodology uses more than 40 building damage models varying with height, age and structural type as well as Modified Mercalli Intensity Scale (MMI), and some spectral acceleration based damage. While both HAZUS and EPEDAT "represent advances in the automated application of loss estimation techniques, the focus of their model development was damage and economic losses, with less emphasis placed on the modelling of casualties" (Seligson et al. 2002). Absent still from the models are the presence of secondary hazards, selected socio-demographics, human behaviour during the event, measures of mitigation and preparedness. Minor injuries treated by self or informally administered first aid are also generally unaccounted for. In order to refine loss estimation models, actual casualty data would need to be integrated with post-event damage appraisals. This in turn requires standardising the way earthquake-related injury data is categorised and collected.

The dearth of casualty research has variously been attributed to lack of funding, lack of people interested in studying it, the challenges of researching with and about survivors, and the complexity involved in unravelling causal factors. The multi-disciplinary demands of this effort call for a variety of social science research methods, including survey research, public health-based epidemiology, and anthropological observation as well as engineering-based casualty modelling, building damage and injury classification schemes. Ethical and professional issues around sharing and coordination have severely impeded progress. As DeVille mourned recently, while hundreds of surveys and studies have been undertaken in relation to recent events, these have been entirely uncoordinated and the results have gone unshared (De Ville de Goyet 2007).

3.2 Rates of Death and Injury

Major published studies of earthquake deaths and injuries up to 1999 are listed Table 3.2. Results are compared in subsequent tables with reference to the events listed in this table. There are some data for 19 earthquakes beginning in 1970. The most comprehensive data are from the Northridge, Loma Prieta, Armenia and Turkey earthquakes. Rates and ratios of deaths and injury available for 13 earthquakes are shown in Table 3.3.

In earthquakes that cause a large number of deaths, the numbers become notoriously unreliable and vary widely. Researchers often depend on official figures that may simply be inaccurate, or may even be deliberately exaggerated or understated for political reasons. In spite of earthquake casualty data being beset by tremendous variation in both data collection and reporting, it seems worthwhile to attempt comparison to see what patterns emerge, where the gaps are and to formulate some hypotheses about mitigation.

For the purposes of comparing relative risk, the first measures sought are the rates of deaths and injuries, often expressed per 10,000 people. Epidemiology and casualty estimation literature tends to report the ratio of injuries to 100 deaths (100D:I) though the simple rate of injuries to deaths may be easier for the layperson to understand (xI:1D). The catchment area used may be a micro-zone, a village, a district, an area within a particular radius of the epicentre, with a particular intensity of shaking, or the entire area in which anyone died, or was injured as a result of the shaking. The wider the catchment area is, the larger the denominator, and the greater the observed ratio of minor to severe injuries. While this makes comparisons extremely difficult, it is nevertheless a starting point. A higher proportion of injuries to deaths are also characteristic of the less lethal events. Most countries count and officially record deaths, so death rates are considered more reliable than injury rates. However, in hyper-lethal earthquakes where deaths number in the tens and hundreds of thousands, and where no relative may be on hand to identify or claim a body, these numbers depend on data collected during what may be mass burials.

While data about level of injuries is can be salutary, collection is beset by complicating factors. The two data sources are health service providers and the survivors themselves. Health service providers may be wide-ranging and in a mass-casualty event may include convergent health providers present for a temporary period of time, remote facilities and informal treatment by convergent responders.

The statement of a leading engineer that, “it is generally agreed that in all vulnerability studies issued to date figures derived for deaths and injuries are of low credibility” (Lagorio 1990) and that of an architect that “there is very little useful data available on the mechanism of injury in building collapse” (Aroni 1990) are as

Table 3.2 Studies of earthquake deaths and injuries

Year	Location	Mag. Int.	Time date day	Dead	Injured	Reference and method
1976	Guatemala [1]	7.5	3:05 Feb. 4 Weds	22,800	76,500	[1] (Glass et al. 1997) Full census in one village
1976	Italy [2]	–	–	–	–	[2] (Tiedemann 1989)
1977	Bucharest, Romania [3]	7.3	21:21 Mar. 4	1,570	–	[3] (Pomonis et al. 1992) Review
1978	Santa Barbara CA, USA [4]	5.7 VIII	15:55 Aug.13 Sun	0	85	[4] (Aroni and Durkin 1985)
1979	Imperial County CA, USA [5]	6.6 VII	16:16 Oct. 15 Mon.	0	78	[5] (Aroni and Durkin 1985)
1980	El Asnam, Algeria [6]	7.3	12:25 Oct. 10	3,500	–	[6] (Pomonis et al. 1992) Review
1980	Southern Italy [7]	6.8	15:34 Nov. 23 Sun.	–	–	[7a] (De Bruycker et al. 1985) Random sample of one-third of villagers in selected area. [7b] (Guha-Sapir 1991)
1983	Coalinga CA, USA [8]	6.7 VIII	16:42 May 2 Mon.	0	211	[8] (Aroni and Durkin 1985)
1985	Chile [9]	7.8 VIII	19:47 Mar. 3 Sun.	180	2,572+	[9a] (Aroni and Durkin 1985) [9b] (Ortiz et al. 1986)
1985	Mexico City, Mexico [10]	8.1	7:18 11:00 Sept. 19	7,700 [10d]	–	[10a] (Durkin and Ohashi 1989) Occupants of two buildings partial cohort [10b] (Durkin 1989) [10c] (Pomonis et al. 1992) Review [10d] (Krimgold 1990). Occupants of Juarez Hospital [10e] (USGS 1985)
1986	San Salvador, El Salvador [11]	–	–	–	–	[11] (Durkin and Ohashi 1989) Occupants of building partial cohort
1987	Whittier CA, USA [12]	5.9	–	–	–	[12a] (Goltz et al. 1992) [12b] (Shoaf et al. 1998)
1988	Spitak, Armenia [13]	6.9	Dec. 7	25,000	31,000 inj. 12,200 hosp.	[13a] (Armenian et al. 1992) Longitudinal study: Cohort = 12,000 hospitalised [13b] (Armenian et al.1997) Longitudinal study: Cohort = Min. Health employees 14 in region [13c] (Noji et al. 1993; Noji 1990b) Geo-stratified random sample of hospitalised and controls [13d] (Noji 1989) [13e] (Noji 1990a) Rapid survey three towns [13f] (Pomonis et al. 1992) Hospital admissions throughout Armenia
1988	Loma Prieta CA, USA [14]	7.1 VIII	17:04 Oct. 17 Tues.	60–67	3,757	[14a] (Durkin et al. 1991) 325 severe injuries/ disabled at work [14b] (Bourque et al. 1993) [14c] (Jones et al. 1993) case-control study with site [14d] (Shoaf et al. 1998)

1990	Luzon, Philippines [15]	7.7	16:28 July 16	1,550+	–	[15] (Pomonis et al. 1992) Review
1994	Northridge CA, USA [16]	6.7	04:41 Jan. 17	33	137 hosp.	[16a] (Bourque et al. 1997) Hospital records, telephone survey [16b] (Mahue-Giangreco et al. 2001) Medical records [16c] (Peek-Asa et al. 1998) Coroner's and med. records [16d] (Peek-Asa et al. 2001) Case-controlled from pop.-based survey [16e] (Peek-Asa et al. 2000) [16f] (Shoaf et al. 1998)
1995	Hanshin-Awaji, Japan [17]	7.2	05:46 Jan. 17	6,308	42,117	[17a] (Osaki and Minowa 2001) Case-control in one city, Nishinomiya, all deaths [17b] (Seligson and Shoaf 2002)) [17c] (Miyano et al. 1996)
1999	Kocaeli, Turkey [18]	7.4 X	03:02 Aug.17	17,480	49,000 med tx.	[18a] (Petal 2009). Family Survey: geo-stratified random sample from Gölcük. [18b] (Erdik 2001) [18c] Kocaeli Governor's Office 2001
1999	Chi-Chi, Taiwan [19]	7.3	01:47 Sept. 21	2,347	8,722	[19] (Liang et al. 2001) Govt. records. Field surveys of medical records at 97 local health facilities

N.B.: Ratios of injuries to deaths have also been reported for the 1963 Skopje, Yugoslavia 6.9M 3.1:1, 1970 Peru 7.8M earthquake of 2.5:1, 1970 N.E. Iran M6.6 2.7:1, 1974 Nicaragua 5.6M 3.3:1, 1974 Pakistan 6.3M 3.1:1, 1976 Friuli Italy M6.5 2.6:1, 1977 Iran 6.9M 3.4:1, 1977 Argentina 7.4M 2.9:1 (Alexander, 1985), and 1976 Tangshan, China M7.8 .5:1 (Bourque et al. 1997).

The numbers in parentheses are based on partial counts. Most do not specify denominators

Table 3.3 Rates and ratios of earthquake injuries and deaths

	Event	Ratio of injuries to deaths	No. of deaths	Rate/ 1,000 pop.	No. of serious injuries	Rate/ 1,000 pop.	No. sought hosp. Tx	Rate/ 1,000 pop.	No. sought med. care	Rate/ 1,000 pop.	No. of minor injuries	Rate/ 1,000 pop.
1976	Guatemala [1]	3.4:1	22,778	50 (one village)	76,500	–	–	–	–	–	–	–
1978	Santa Barbara, CA [4]	–	–	–	3	0.02	85	0.6	–	–	–	–
1979	Imperial County, CA [5]	–	–	–	4	0.08	78	1.5	–	–	–	–
1980	Southern Italy [7a]	3.2:1	–	93	–	–	–	–	–	–	–	–
1983	Coalinga, CA [8]	–	–	–	17	2.3	211	29	–	–	–	–
1985	Chile [9a]	14:1	180	–	(137) [9b]	–	2,572	–	(1,025) [9b]	–	–	10,000
1985	Mexico City, Mexico USGS 1985 [10e]	3.2:1	–	–	–	–	–	–	–	–	–	–
1988	Armenia [13]	23:1 trapped [13e]	24,000	(494)	12,200	–	–	–	31,000	–	–	–
1989	Loma Prieta, CA [14]	90:1	63*	–	(325**)	–	–	–	–	–	–	–
1994	Northridge, CA [16]	4.2:1	33	0.0037 [16c]	–	–	144 [16d]	0.0156	30,000 extrap	9	240,000 extrap	82
1995	Hanshin-Awaji, Japan [17]	6.8:1	6,308	–	–	–	–	–	42,117	–	–	–
1999	Kocaeli, Turkey [18]	0.5 severe: 1 2.8 mod: 1	17,480	10 av. 4–40 [18a]	–	–	9,477 [18c]	–	49,000 [18b]	20	–	–
1999	Chi-Chi, Taiwan [19]	–	2,347	0.148	8,722	–	–	–	–	–	–	–

*42 viaduct, 17 at work ** disabled at work

The numbers in square brackets refer to events and references listed in Table 3.2.

true today as they were almost 2 decades ago. Notwithstanding the low credibility of these figures and the wide variation in them, they have been used to yield a 3:1 or 4:1 rule-of-thumb for the rate of hospitalised injuries to deaths in earthquakes of magnitude 6.7 and above (Bourque et al. 1997).

Standardised injury classification is vital to our ability to understand the wide range of data and make useful comparisons. Many factors complicate data collection; services may be provided by multiple providers, moderate injuries often become serious and even life-threatening when not treated, and presentation at hospital may depend on the availability of hospitals and the scale of the event. In a smaller event people with less serious injuries are likely to present themselves at a hospital for a higher level of service, whereas in larger scale events these may present themselves to field clinics for a walk-in level of care. Injuries that require medical treatment, but not hospitalisation are only mentioned in the literature of four earthquakes: Kobe, Northridge, Armenia, and Chile. Injury severity data, distinguishing between slight, moderate, severe and fatal injuries are also vital, but such data have only been clearly differentiated in data from California and Turkey.

3.3 Key Variables and Findings

Key variables have emerged in the literature over the years with each discipline contributing to the definition of variables it works with most frequently. Seligson and Shoaf (2002) propose a classification scheme that standardises most of the variables found in the literature of interest to both healthcare professionals and engineers, with individual, building and hazard level variables. The framework proposed here modifies building level variables to include built environment variables, and adds mitigation and response level variables also found in the literature:

Individual level variables**:** demographics, injury characteristics, location, activity, occupant behaviour.

Built environment level variables**:** construction type, quality of construction, storey height, building damage, collapse pattern, volume loss, extrication difficulty, non-structural risks, infrastructure risks, hazardous materials exposure.

Hazard level variables**:** earthquake source characteristics, local site hazard characteristics (include post-impact data as well as environmental factors such as temperature).

Mitigation level variables**:** household preparedness, fastening tall and heavy furniture, having fire suppression tools and knowledge, first response skills and response provisions.

Response level variables**:** time of arrival, availability of professional rescuers, length of time entrapped, response effectiveness, presence of trained community emergency response volunteers.

Table 3.4 Demographics of deaths and injuries

Event	Variable
Guatemala, 1976	Youngest child safer, penultimate child more at risk. Risk increasing with age over 45. Females elevated risk of death and esp. injury [1]
Santa Barbara, CA, 1978	Young, male [4]
Imperial County, CA, 1979	A few more women [5]
Southern Italy, 1980	Ages 5–9 at increased risk [7]
Coalinga, CA, 1983	Elderly (especially falls), disabled, slightly more women [8]
Whittier Narrows, 1987	[12b] No significant difference in ages [12]
Loma Prieta, CA, 1989	[14d] Injured older than non-injured (57.9 versus 45.8 years) [14]
Northridge, CA, 1994	[16b] Over 60 years had 6.1 × risk of death than 30–39 year olds. In over 50 relative to 30–39 age groups, injuries were 2.7 × higher. More treated in 30–39 than other age groups. No gender association with more severe injury. [17a] Women, white, younger more likely to report injury. [16f] Injured younger than non-injured (37.3 versus 41.3 years)
Hanshin-Awaji, Japan, 1995	Over 50 years old. [17b] Due to living on ground floor and in older, more vulnerable, buildings. Physical disabilities OR 1.9 [17c] More than 50% of dead >60 years. Higher rate among females
Kocaeli, Turkey, 1999	Women slightly higher rates of deaths and injuries. Not related to severity, time or activity. Children 7–19 more likely to die. Adults 30–49 more likely to be injured [18a]
Chi-Chi, Taiwan, 1999	Elderly, fragile minorities, children. Higher rates of death for those over 20 years. 80 years and older – 0.8 per 1,000, 70–79 years – 0.05; children 0–9 years –0.13 and 10–29 years – 0.07 [19]

The numbers in square brackets refer to events and references listed in Table 3.2. OR[1]= odds ratio

Table 3.5 Part of body involved in fatal injuries

Event	Variable
Chile, 1985	Head, multiple trauma [9a]
Northridge, 1994	Thorax (42%), head (39%), abdomen (21%) [16a]
Kocaeli, Turkey, 1999	Neck (67%), head (33%), chest (33%) [19a]

The numbers in brackets refer to events and references listed in Table 3.2

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[1] The odds ratio compares the probability of occurrence between exposed and unexposed groups. An odds ratio of 1 means that the impact is equally likely for both groups.

Factors such as time of injury span both hazard and occupant behaviour. Untangling the interactions of these variables is unavoidably complex. The available data from those earthquakes so far studied (those in Table 3.2) are summarised in Tables 3.4 through 3.13 below.

3.4 Individual Level Variables

3.4.1 Demographic Characteristics

An emerging and consistent finding is that increasing age is associated with higher mortality. There are many possible reasons for this: more fragile, less mobility, less able to avoid falling objects, more prone to falling, living alone and with less assistance, less will to live.

In several earthquakes women have been found to be more vulnerable than men, usually attributable to social roles, division of labour and location at the time of the earthquake and possibly gender-specific behaviour. In the February 2002 Afyon earthquake which occurred on a Sunday morning and affected rural villages, injury rates for women attending to animals in the barn, and grandparents and young children who remained indoors were noticeably higher than those of men, and the age-group between, who were outside attending to chores (Petal 2009). These and other observed socio-cultural factors associated with gender and age (including social division of labour) are of particular importance to public education advice.

Table 3.6 Parts of body involved in survived injuries

Event	Variable
Santa Barbara, CA, 1978	Arms, hands, feet [5a]
Imperial County, CA, 1979	Arms/hands, back, head/face [6a]
S Italy, 1980	39% Legs, 23% head, 19% chest, 16% arm [7a]
Coalinga, CA, 1983	Arms/hands, head/face, feet [8]
Whittier Narrows, CA, 1987	41% Minor head injuries [12b]
Loma Prieta, 1989	55% Trunk or torso [14e]
Northridge, 1994	68–82% Extremities [16f] 54% lower or 19% upper extremities [16a]
Kocaeli, Turkey, 1999	24% Feet, 19% legs, 15% hands, 10% head, 8% back, 7% shoulder, 5% arms, 3% each neck, chest, hips, 3% other. 46% multiple injuries [19a]

The numbers in square brackets refer to events and references listed in Table 3.2

Table 3.7 Occupant behaviour and deaths and injuries

Event	Variable
Peru, 1970	Running out into wide streets protective. Running out into narrow streets hazardous [1a]
Italy, 1976	Running out crushed by falling masonry. [3a]
Santa Barbara, CA, 1978	Broken glass [5a]
S. Italy, 1980	55% Ran outside; 40% of those who stayed inside were injured, 28% of those who ran outside were injured [7a]
Coalinga, CA, 1983	Leaving building, falls, hit by objects, 16% glass [8]
Whittier Narrows, CA, 1987	Take cover in doorway, hall or under furniture 43% at home 40% at work. Stayed in place 20%. Going outside 9% home, 18% work. Pull to side of road if driving 46%. Run out 50% of those exiting [12a]
Armenia, 1988	Staying in versus running out after first shock OR 4.40% (2.24–8.71) [13a]
Loma Prieta, CA, 1989	60% of workplace severely injured took protective action (43% of these attempting to evacuate or move to safer place, 24% duck cover hold, 14% in doorways) [12a]
	Freeze in place or seek protection 72%. 42% of those with children went to them. Staying in place increases with age. Running outside associated with males and fear. Fear associated with seeking protection. More experienced, stay in place [12b]
	Increased injury trying to rescue OR 2.08 (1.36–3.18) and trying to exit OR 1.93 (1.63–3.82). Decreased injury with standing under doorway OR .51 (0.33–0.78) and holding on to something OR 0.58 (0.39–0.86) [12c]
Northridge, CA, 1994	15% jumping out window, catching falling tv etc. Of those who attempted to move 10.4% inj. versus 6.1% of those who stayed in place [16f]
Kocaeli, Turkey 1999	76% of injured/dead were sleeping. 20% were in bed awake. 4% were standing or sitting awake. Of the non-injured 84% were sleeping. And 16% were awake. 79% of dead died during the shaking, 5% running down stairs and 8% while awaiting rescue. 52% of injured were injured during the shaking, 23% while exiting during, 15% while exiting after [19a]

The numbers in square brackets refer to events and references listed in Table 3.2

3.4.2 Injury Characteristics

Unfortunately there are very little consistent data on earthquake injuries. Injury severity can be fairly easily differentiated into four levels: minor (first aid), medical care required (outpatient), serious (life threatening/hospitalisation required) and fatal (as the HAZUS methodology does) (NIBS and FEMA 2003). However there are few results reported for comparison. Injury typology for earthquakes based on an adaptation of the Abbreviated Injury Scale (AIS) (developed by the Association for the Advancement of Automotive Medicine) usefully includes: cause of injury (esp. structural/non-structural relatedness), secondary hazards (e.g. fire,

Table 3.8 Injuries and deaths: building damage

Event	Variable
Spitak, Armenia, 1988	High occupancy collapsed or heavily damaged buildings responsible for fatalities [13d]
Loma Prieta, CA, USA, 1980	Damage to building components OR 10.36 (3.27–44.9)
	Damage to contents OR 2.95 (1.83–4.76) [14c]
Northridge, CA, USA, 1994	Most buildings damaged do not lead to occupant injury. Areas with highest number of injuries per building were among areas with least percent of buildings damaged [16a]
Hanshin-Awaji, Japan, 1995	Increases with damage level of building, especially with age and disability [17a]
Kocaeli, Turkey, 1999	23% of those in more damaged homes suffered death or injury. 86% of injured and dead in buildings damaged beyond repair. 71% of fatalities were in destroyed buildings and 29% in those with major damage. In less damaged homes only 5% were injured. High proportion of moderate injuries occur in less damaged buildings [18a]

The numbers in square brackets refer to events and references listed in Table 3.2

landslide, tsunami, hazardous materials) as well as mechanism, injury severity and treatment (Seligson and Shoaf 2002).

Fatal injury characteristics are consistent: head, neck, and thorax injuries are the most lethal.

Commenting on injuries sustained in the Northridge earthquake, researchers note that lower extremity injuries were modal and that upper-extremity injuries were more severe (2.6 times risk of more serious injuries compared to lower extremities). Falls were also more serious (5.3 times greater than being struck or cut by objects). There has been little differentiation by severity of injuries. Whereas in three California earthquakes most injuries were minor (Shoaf et al. 1998) in Kocaeli, Turkey, 47% were minor, 45% moderate and 8% serious (Petal 2009).

While emotional injuries have not been systematically reported in the epidemiology literature, in 1994 in Northridge 32–36% of those seeking care reported emotional injuries (not clinical levels of distress) (Bourque et al. 1997). In Kocaeli, Turkey, in 1999, 13% continued to seek mental health treatment after 20 months. One percent were identified as mentally disabled as a result of earthquake. Specific problems reported were: tension (40%), depression (26%) and fear (25%) (Petal 2009).

3.4.3 Occupant Behaviour

Commenting on occupant behaviour Mahue-Giangreco et al. (2001) note that

Table 3.9 Building construction type: damage impact on lethality

Event	Lethality & construction type
Bingol, Turkey, 1971	5.26% lethality for occupants in destroyed stone rubble/stone masonry buildings with heavy rammed roof (Pomonis et al. 1991).
Caldiran, Turkey, 1971	11.07% lethality for occupants in destroyed stone rubble/stone masonry buidlings [21a]
Guatemala, 1976	100% of deaths and serious inj. in adobe. In one village relative risks much higher than with previous lightweight bajareque construction (Pomonis et al. 1991)
Bucharest, Romania, 1977	>70% of 1,500 deaths in reinforced concrete [4a]
El Asnam, Algeria, 1980	>40% of 3,500 deaths including 500 deaths in a single market/residential complex reinforced concrete [15]
Erzurum, Turkey, 1983	8.32% lethality for occupants in destroyed stone ruble/stone masonry (Pomonis et al. 1991)
Chile, 1985 [9]	53.6% of deaths and inj. in unreinforced stone
	33.3% of deaths and inj. in other masonry
	5.8% of deaths and inj. in reinforced concrete
	5.8% of deaths and inj. in wood-frame
Mexico City, 1985	>90% of all deaths in reinforced concrete. 39–59% of occupants of three high-occupancy buildings killed [10c]
Spitak, Armenia, 1988 [13e]	2.8% lethality ratio in 38 destroyed stone masonry buildings, 12% in masonry
	84.4% in ten destroyed reinforced concrete buildings
	46% in pre-cast concrete – most lethal
	87% in frame panel (highest mortality rate per building)
	47.5%–97% of pre-cast reinforced concrete frame buildings = approx 30% of all deaths [13f]
Luzon, Philippines, 1990	56–61% of occupants of 11 collapsed reinforced concrete buildings [15] >75% of 1,550 + deaths [15]
Northridge, CA, USA, 1994	Lightweight wood frame predominant type/cause [16b]
Kocaeli, Turkey, 1999	Reinforced concrete, moment-frame predominant type/cause [18a]
	1.7% in partially collapsed buildings and
	10.7% in totally collapsed buildings (actual rates may be as much as twice as high) [19a]

The numbers in brackets refer to events and references listed in Table 3.2

Actions such as reaching for or catching objects might leave the upper extremities particularly vulnerable to more serious injuries. Alternately, people may be more likely to brace themselves with their arms, exposing them to more environmental hazards. Traditional recommendations have included instructions to ‘duck, cover, and hold’ which have been questioned in current studies. How one ‘holds’ might be better described, and maintaining a compact, tucked position (as recommended for airline crashes) might also be a more appropriate response, particularly if one is not ambulating. (Mahue-Giangreco et al. 2001).

Table 3.10 Injuries: height of building and on which floor

Event	Variable
S. Italy, 1980	Increased deaths with greater number of floors [7a]
Spitak, Armenia, 1988	Five floors or more OR 3.65 (2.12–6.33) [13.1]
	Floors 2–4 versus 1 OR 3.84 (2.18–6.79)
	Floors five or more versus floor 1 OR 11.2 (3.62–37.03)
Kocaeli, Turkey, 1999	1–3 floors account for 31% of households, 0% dead and 18% of injured
	4–6 floors account for 52% of households, 62% of dead and 62% of injured
	7+ floors account for 16% of households and 36% of dead and 20% of injured [18a]

The numbers in square brackets refer to events and references listed in Table 3.2

The authors recommend further study of that question. In California, in the Imperial County earthquake in 1979 investigations of the behaviour of occupants of one office building suggest that about half of the people injured may have been engaging in unnecessary evasive behaviour, bumping themselves on desks and in doorways. Evacuating unreinforced masonry buildings during the shaking appears to increase the risk of injury by a factor of 3 (Aroni and Durkin 1985).

One of the human behaviour variables that has been treated by some authors as an independent variable is “exiting the building”. If occupants exit and are injury-free this is interpreted as a protective action; if they are injured it is interpreted as dangerous. In Armenia, for a subgroup of cases and controls who moved after the first shock, those who ran out were safer than those who stayed within (Armenian et al. 1992). Others have alluded to exiting being safer as well (Roces et al. 1992; De Bruycker et al. 1985). In addition to the very limited building types referred to in these studies, there are methodological problems in the literature to date. The first error is to refer to this variable as independent. The already injured may not be able to exit during the shaking to be counted. As is acknowledged in one study, “It’s possible that many of the cases were unable to run out of the building because of their injury” (Armenian et al. 1992). In buildings that suffer damage, people may have a much more difficult time exiting and suffer more injuries inside before eventually getting out.

The second error is that if exiting is really dangerous, then people killed while exiting are not available as informants. The third error is that the ability and impact of exiting is likely to be related to distance from epicentre (severity of ground-shaking), time of exit, number of floors, where exiting from, where exiting to (for example, construction type, building height, and hazards immediately outside the building). The question for public education is whether being injured exiting might be relatively less or more harmful than remaining inside. Peek-Asa et al. (2001) note that the disparate findings between Armenia and California are “not necessarily contradictory because exiting from a poorly-built collapsing structure may protect against death while attempts to exit buildings that do not collapse may increase risk for injury”. It is especially important therefore for authors drawing

Table 3.11 Causes and types of injury

Event	Variable
Guatemala, 1976	Adobe blocks (82%) [2a]
Santa Barbara, CA, 1978	Bumped, hit by objects, falling, leaving building, broken glass [5a]
Imperial County, CA, 1979	Lacerations/abrasions, contusions, fractures/sprains, back injuries, anxiety [6a]
S. Italy, 1980	Lacerations (42.4%), contusions (26.5%) fractures (18.9%) cuts (9.7%) [7a]
Coalinga, CA, 1983	Lacerations/abrasions, contusions, fractures/sprains, head injuries [8]
Chile, 1985	Non-structural and building contents [9a]
Whittier Narrows, CA, 1987	Emotional (23%) Falls (19%) Non-structural (about half) [12b]
Armenia, 1988	Failure of buildings. Entrapped victims. Being inside a building. Height five floors or more. [13a] Being inside a building. Height of building. Location on upper floor. [13b] Hypothermia, crush syndrome (9.5%), asphyxiation. Multiple injuries (13e) (39.7%) Superficial trauma (24.9%), head injuries (22%), lower extremities (19%), crush syndrome (11%), upper extremity trauma (10%) [13a]
Loma Prieta, CA, 1989	Strains, sprains, contusions (60–70%) from falls and evasive action. Fractures and lacerations 16% [14a] Cuts, bruises and sprains (45%) Non-structural less than 10% of injuries. Falls (55%) Car moved and injured (27%) [14d]
Northridge, CA, 1994	Objects fell or broke (54%), own behaviour (15%) [161] Of hospitalised fell (56%) or hit by objects or tried to catch something (6%) Falls associated with more serious injuries than other mechanisms [16b] Falls or hit by objects, also motor vehicle and burns. [16c] Minor injuries mostly non-structural and falls. [16c] Hospitalised injuries hit by objects (15%), hit by building parts (8%) [16c] Cuts, bruises and sprains (83%) [16f]
Hanshin-Awaji, 1995	Hospitalised injuries crushed or pinned (59%) Hit by falling materials (19%) falls (8%) [17b] Burns (2%) (esp to older women who were cooking) [17c]
Kocaeli, Turkey, 1999	Injuries: struck by falling object (33%), being under falling object (24%), cutting or piercing object (11%), fall (8%), other (3%), multiple (20%). Deaths: being under falling object (71%), struck by falling object (26%), both (3%) [19a]

The numbers in square brackets refer to events and references listed in Table 3.2

Table 3.12 Cause of deaths and injuries: structural/non-structural

Event	Deaths: Structural	Deaths: NonStructural	Deaths: Both	Non-fatal injuries: Structural	Non-fatal injuries: Non-Structural	Injuries: Both
Loma Prieta, CA, 1989 [14a]	98.5%	1.5%		7% 32% of hospit.	22% of inj. 8% hospit.	
Northridge, 1995	75.8% [16a]			13% [16a] <1% [16f]	44% of hospit. 55% of inj. [16f]	
Kocaeli, Turkey 1999 [19a]	61%	26%	13%	22%	69% of inj.	11%

The numbers in square brackets refer to events and references listed in Table 3.2

Table 3.13 Hit by object

Event	Variable
Imperial County, CA 1979 [6.a]	Moving desks, filing cabinets and furniture in immediate vicinity
Whittier Narrows, CA 1987 [12b]	Non-structural caused approx. half of injuries
Loma Prieta, CA, 1989 [14a]	Tall metal lockers, wine barrels, heavy filing cabinets, hazardous materials
Kocaeli, Turkey 1999 [19a]	Non-structural objects: free-standing cabinet 29%, glass objects 13%, wardrobe 11%, drawers/buffet 6%, window 6%, 24 other causes 35%. Structural objects: ceiling or beam 40%, infill walls 28%, columns 16%, other 10%

The numbers in square brackets refer to events and references listed in Table 3.2

conclusions about behaviour to be specific about the construction type, number of floors, and external environment, to avoid unwarranted generalisations.

There are similar problems with other occupant behaviour. For example, the minor injuries sustained by people diving for cover under a desk, or being hit by the door as they stand in the doorway, may be tolerable because the victim is in fact avoiding greater injury. It seems that there is a need for more penetrating and open-ended interviews with survivors when it comes to exploring the efficacy of certain protective behaviour.

People's responses during an earthquake are by now a combination of instinctive and learned responses that vary depending on where they were at the time, the intensity of shaking, and probably the behaviour of others present, and prior training or education received. While in disasters with warnings, panic is rare, the rapid onset of earthquakes tend to trigger primitive emergency responses, i.e. freeze, flight and fight. Based on tornado response research it appears that males tend to assume leadership with males present, and females with children present. Most people seem to react to help people rather than protect property. However, in the case of earthquakes it appears that some people move to catch falling objects.

3.4.4 Individual Behaviour – Time of Injury

The question of when people are injured indicates a substantial number of injuries after the event. Few conclusions have been drawn from this in the literature, but a reasonable hypothesis is that this is likely to be a combined function of behaviour, and the impact of aftershocks.

When it comes to non-fatal injuries, 8–39% have been found to occur after the main shock (mostly within minutes of onset). In Turkey 13% occurred just after, 2% during search and rescue, and 1% each during aftershock and during clean-up (Petal 2009). While in Turkey virtually all fatalities occurred during the shaking

(Petal 2009), in two California earthquakes, from 15–18% of fatalities occurred more than a few minutes later (Durkin et al. 1991; Bourque et al. 1997).

3.5 Built Environment Level Variables

Human casualty estimation in the earthquake engineering literature has been based on formulae such as K = Ks + K' + K2 where Ks is fatalities due to structural damage, K' is due to non-structural causes, and K2 is due to secondary hazards (Coburn and Spence 1992). The most important variable is building type. Modifying factors include soil-structure interaction, storey height, location relative to other buildings. Function and occupancy may also be factors. In addition, construction quality, location inside or outside, and specific non-structural building elements and building content hazards are all important.

3.5.1 Building Damage

The use of standard building damage classification schemes such as ATC-13 (Applied Technology Council 1985) would enhance comparability of data. It is axiomatic that more damage is associated with more fatalities, but just how much more, and how significant are the incremental benefits of structural safety measures? In Turkey, data from the prevalent reinforced concrete moment frame buildings suggests that the very small proportion of buildings that suffered pancake collapse were responsible for the vast majority of fatalities. Fatality rates in heavily damaged buildings were 1.5 per 100 by comparison with 10.7 per 100 in totally collapsed buildings (Petal 2009). A litany of poor design and construction practices are implicated in these collapses (Erdik 2001).

Counter-intuitively, in Northridge, areas with the lowest percentage of buildings damaged had the highest number of injuries. These findings alone bring us a significant step beyond the 'rules of thumb' correlations between buildings damaged and casualties.

3.5.2 Inside or Outside a Building, Building Function and Occupancy

Location is characterised mainly as either inside or outside a building. While data from daytime rural earthquakes indicate that being inside a building is more hazardous than being outside a building, similar data do not exist for dense urban environments where high foot traffic occurs in narrow streets lined with multi-storey buildings and overhead wires. It would be folly to extrapolate from one setting to the other.

The function of the buildings that are associated with increased morbidity and mortality depends largely upon the time of day of the earthquake. Earthquakes that occur during the middle of the night of course take their toll mostly at residences. During commute hours, roads may account for a large number of deaths. However, earthquakes that take place during the working/studying/shopping day will take their toll throughout the urban environment.

The question of location within a building has so far been looked at only in a superficial way, and not with respect to some important variable that may be linked to construction type, such as location by an interior or exterior wall, or location by a column, in a smaller or larger room, or in rooms with different functions (kitchen, bedroom, bathroom, office) where the hazards may differ. In Guatemala, location near corners and doors of adobe houses did not confer greater protection (Glass et al. 1977).

3.5.3 Building Construction Type

During the first half of the twentieth century, most earthquake fatalities were related to the collapse of masonry buildings (adobe, rubble stone, rammed earth fired-brick and concrete-block). By the second half of the twentieth century the proportion of deaths related to concrete-frame houses had risen dramatically.

> Concrete-frame houses are generally safer (i.e., less likely to collapse), but they are also vulnerable, and when they do collapse, they are considerably more lethal and kill a higher percentage of their occupants than do masonry buildings (Noji 1997c).

Evidence of the increasing implication of concrete buildings in earthquake deaths comes from several urban earthquakes over the last 35 years, just because this has become the predominant construction type in dense urban areas.

The lethality ratio in collapsed multistorey reinforced concrete structures ranges between 20% and 97% (Pomonis et al. 1992). While less vulnerable overall, the lethality ratio of these buildings is much higher than other traditional building construction types. Overall 75% of earthquake deaths are attributed to the collapse of buildings (primarily masonry but increasingly reinforced concrete) (Spence 2003).

3.5.4 Building Construction Quality and Year of Construction

In Spitak, Armenia, poorly designed buildings constructed in the late 1970s and early 1980s were heavily damaged. Similarly in Turkey, in 1999, poor design, materials, and construction quality were responsible for the higher rate of collapse of newer buildings. Although no study has yet compared impacts of building level specific seismic safety measures, it is clear that as far as fatality prevention “the most effective preventive effort … would have been appropriate structural approaches prior to the earthquake”. (Armenian et al. 1997)

Year of construction can usefully be tied to the timing of the introduction or enforcement of a seismic building codes and general changes in construction practices as well as to the pressures of in-migration peaks and other time-sensitive phenomena. In Northridge, in 1994, buildings constructed prior to 1960 had 4.6 × risk for serious injury compared to those built after 1975 (Mahue-Giangreco et al. 2001). In Turkey, in 1999, buildings constructed after new codes in 1976 suffered more damage. Spectral characteristics of the earthquake exceeded the design level indicated in the code. Mean year of construction for uninjured is 1980, for injured, 1983 and for dead 1986. Rapid urbanisation and self-built reinforced concrete buildings are considered to blame (Erdik 2001; Petal 2009).

3.5.5 Building Height and Floor

Direct correlation has been established between building height and the increased likelihood of deaths and injuries. There is some evidence from Chile that relative greater motion on higher floors of apartment buildings may restrict people from taking protective action (Aroni and Durkin 1985). In Armenia (Armenian et al. 1992) and Turkey (Petal 2009) upper floors pose greater risks, though it is not clear whether this is due to ductility, non-structural hazards or the sorry combination of poor design and construction of taller buildings. In Japan, the first floors of wooden buildings were found more hazardous than the second (Miyano et al. 1996).

3.5.6 Structural and Non-Structural Causes of Injuries and Deaths

While engineering studies have almost always estimated deaths and injuries based on a correlation with structural damage, there is evidence that the picture is considerably more complex.

> Although most injuries from falls or from being struck by nonstructural elements are minor compared with those sustained as a result of building collapse, some physical objects (e.g., tall metal lockers, wine barrels, heavy filing cabinets) and some settings (e.g., stairwells) are particularly hazardous and can cause serious injuries. (Noji 1997b).

In Armenia, where structural damage was clearly responsible for most deaths, non-structural infill masonry, panels and bricks killed people both inside and outside. Non-structural elements collapse (e.g. parapets) also caused serious injuries (Noji 1990a).

In Chile in 1985 many injuries occurred in buildings with no apparent structural damage, although the causes were not uncovered (Aroni and Durkin 1985). Based on observations from Imperial County in 1979, where the ratio of building contents-related o other non-structural injuries was 3:1, researchers suggest that

> … in addition to the traditional non-structural abatement measures of securing suspended ceilings and lighting fixtures, we need to secure or reposition building contents in areas where people spend most of their time. This finding illustrates the necessary interplay of engineering and preparedness practices (Aroni and Durkin 1985).

In the Northridge earthquake, too, it was found that while structural damage continues to be associated with mortality, it is not the only or even the primary factor associated with morbidity. Being hit by building parts was related to the highest PGA values, being hit by objects was related to lower PGA areas. Both kinds of injuries were abundant over a broad range of PGA values. Furthermore, fatal or severe injuries were reported in 8.8% of the zip codes areas with no damage (Peek-Asa et al. 2000).

> Injuries occurred "primarily because objects fell from shelves or walls, because parts of buildings fell, because of how the injured person behaved during or immediately after the earthquake, or because the person fell during the earthquake" (Goltz et al. 1992).
> One of the most important things this study shows is that structural damage was not associated with more serious non-fatal injuries. Structural characteristics have been associated with fatal injuries in many earthquakes. However, our study shows a paucity (1%) of injuries caused by structural collapse or partial collapse (Mahue-Giangreco et al. 2001).

This finding is attributed to the protection afforded by application of improved building codes. More than one group of authors note that "Structural reinforcement of the home is emphasised in earthquake preparedness activities, with only secondary attention paid to securing non-structural items such as bookcases and heavy furniture." Shoaf et al. (1998) suggest that given the strong association of injury with non-structural hazards, there is a missing emphasis in public preparedness.

Content-related injuries seemed to be higher in concrete and metal structures and lower in wood buildings in the Loma Prieta earthquake (Jones et al. 1994). This may well be an effect related to building height.

3.6 Hazard Level Variables

3.6.1 Seismic and Geophysical Factors

In an innovative study, Peek-Asa et al. matched 105 geo-codeable injuries of victims over age 18, in the Northridge earthquake to age and gender-matched, and location-matched pairs. While damage to buildings is the strongest predictor of death and injuries in most studies, this research team noted that multivariate studies have uncovered other important factors, most notably that "earthquake-related fatalities and hospitalised injuries extended far beyond the epicentre of the earthquake and were not equally distributed around the epicentre" (Peek-Asa et al. 2000). The radius for severe injuries was wider than that for lethal injuries and the radius for minor and moderate injuries was widest. Most lethal injuries were between 10 and 20 km from the epicentre. "Injury incidence and severity… had strong relationships to ground shaking and building damage, but injuries were widespread throughout the region. Most of the linear variation in injury rates were not explained by ground shaking and building" (Peek-Asa et al. 2000).

3.7 Mitigation Level Variables

3.7.1 The Value of Preparedness

The impact of preparedness on casualty-reduction has been studied very little. In Northridge, average respondents had done two of 12 preparedness activities, somewhat protective in preventing injuries (Mahue-Giangreco et al. 2001). In Turkey there was an overall increase of 100% in nine household hazard adjustment measures after, versus before the earthquake, strongly indicating that survivors themselves consider these measures to be valuable. Securing tall and heavy furniture increased fivefold. Prior to the earthquake 18% of these measures were being taken, though not primarily for earthquake preparedness (e.g. keeping a torch, extra water). In the absence of a systematic public education programme only 62% of these measures were being taken 20 months afterwards (Petal 2009). Whereas fire drills and high-rise evacuation practice are demonstrably important in saving lives, there is also some evidence that earthquake drills promote orderly evacuation and prevent injuries (Aroni et al. 1982).

3.8 Response Level Variables

3.8.1 Entrapment, Rescue and Medical Response

Whether a person is trapped or not, and for how long has a significant bearing on mortality and severity of injury (Coburn and Spence 1992). Depending on construction type, many people are able to extricate themselves, or are helped by other members of their household. The first day, known as the "golden day", is when most live rescues are accomplished. In Italy 93% of those rescued within the first 24 h survived. There are indications from adobe buildings in Turkey and China that after 2–6 h less than 50% of those entrapped are still alive (De Bruycker et al. 1985).

In Armenia, in an immediate post-earthquake survey of deaths and injuries in three towns within rural areas (pop. 8,500) death rates were 67 times higher among trapped victims and injury rates were 11 times higher among trapped victims than among those who had not been trapped. In a survey sample 58.8% of uninjured controls were rescued in the first hour, versus 33.8% of the hospitalised injured. While being trapped is clearly linked to injury and death, it is not yet clear under what conditions extrication from reinforced concrete rubble has a measurable impact on survival. Pomonis et al. (1992) tentatively conclude from reviewing earthquake building collapse studies, that the most important factors are "the collapse pattern or the amount of voids created within the debris," the number of storeys and the quality and effectiveness of SAR operations. The size and number of void spaces, and void-to-volume ratio of collapsed buildings affect survivability, and these in turn are impacted by construction type and design features of buildings. Different construction types require different lengths of time to penetrate for rescue. The suffocating dust-producing potential of construction materials increases lethality. Jones et al. (1994) also looked at "being prevented or slowed from exiting a building due to earthquake-induced debris" in the Loma Prieta earthquake and found an odds ratio of 6.00 (1.34–26.91) for increased risk of injury.

In Armenia in one town, 89% of those rescued alive were extricated in the first 24 h (Noji 1990a). The average extrication took 50 man-hours (Noji 1989). It has been suggested that many deaths might have been prevented had victims received medical attention during the first 6 h (Pretto and Klain 1992). In Italy, one study concluded that life-saving first aid might have saved the lives of 25–50% of victims who died slowly (Safar 1986). Survival modelling reinforces the reality that the longer it takes to rescue someone, the worse their chances of survival. "Fade-away time" indicates that entrapment time and death are affected by pre-entrapment health condition and weather and air supply (Pomonis et al. 1991) (referring to the Shiono Krimgold SAR model). Air supply is in turn affected by construction type. A critical mass of injuries may also reduce rescues (mostly performed by uninjured survivors in the immediate vicinity) (Coburn et al. 1989). In Taiwan, a high number of casualties (2,000+) were spread out over 12 counties. Even though hospital beds and physicians per population were relatively high, high demand impinged on the quality of care, and transportation disruption resulted in many people not getting medical intention in time to avoid permanent disability or death. Lessons learned in Taiwan led to the establishment of new modular disaster medical teams with adequate logistic support, more locally based disaster medical teams, and more multidisciplinary search and rescue teams (Liang et al. 2001).

In Southern Italy (De Bruycker et al. 1985), Mexico City (Durkin and Ohashi 1989) and Armenia (Noji et al. 1990) it was found that 80–90% of household members and neighbours were responsible for rescues. In Armenia, the catastrophic nature of the event rendered a higher ratio of injured in the local population with fewer able to participate in rescue (Noji et al. 1993). This reinforces the widely-known ineffectiveness of international search and rescue response (De Ville de Goyet 2007) and suggests that making even modest gains in reducing structural damage and injuries will have a significant multiplier effect when it comes to early extrication.

In spite of the dramatic drop off rate of live rescues, wherever thousands are entrapped in collapsed reinforced buildings, the cessation of search and rescue activities prior to uncovering all survivable void spaces, will mean many people buried alive and without rescue attempt. While certainly a costly intervention, much work is still to be done to identify those entrapped alive, sustain them through extrication, and increase their chances of survival.

The question of whether and where medical treatment was sought has been little studied, and the vast differences between both casualties and facilities offers little opportunity for meaningful comparison. However, an important collateral finding from the Northridge earthquake has immediate implications for public education and merits further investigation. People unable to return inside damaged buildings lost access to their medications for heart disease, blood sugar, hypertension and other life-threatening conditions as well as mental illnesses. Not having their prescriptions, knowing their medication and dosages, and with medical records inaccessible due to structural or non-structural damage to physicians' offices, these individuals suddenly presented to emergency rooms with potentially difficult medical needs.

3.9 Discussion

Over the course of epidemiological and loss estimation research only a few authors have made recommendations for public education based on their findings, sometimes diminishing their significance by incorrectly referring to them as 'common sense', before they have become such. The body of research allows us to make several important evidence-based recommendations for public safety.

Structural safety measures: The evidence for building and maintaining seismic-resistant buildings is overwhelming. Indeed buildings do kill people. However, equally important for the self-builder, or for prioritising minimum retrofit is the evidence that simply by preventing building collapse the worst mass fatalities can be mitigated. Therefore limited resources can be effectively applied to incremental seismic-resistant design and construction measures (including minimum retrofit).

Non-structural safety measures: Building non-structural elements and building contents are implicated in deaths and injuries. Public education can usefully emphasise knowledge and skills to identify and mitigate items that can slide and fall, to secure tall and heavy furniture, electronics and appliances, to keep exit pathways clear, fasten hanging objects, store heavy objects lower down, place beds away from windows, and use tempered glass and window coverings.

Response skills and provisions: A strong evidence-basis exists for the advice to avoid potential falling objects and to either stay in bed, or adopt 'the earthquake position' wherever possible. This means to get down low (to prevent falling, and to allow taller compact objects to catch flying and falling objects – under a table or next to a low piece of furniture, make yourself small (to be a smaller target and to avoid injuries to extremities), cover your head and neck (the most vulnerable parts of the body). Exiting during shaking is advised only when early primary waves can be distinguished or when on the ground floor of an adobe or stone building with heavy roof and where there is a safe place to exit. Since family, friends, co-workers and neighbours immediately on the scene are true 'first responders', community-based programmes teaching incident command systems, light search and rescue skills (emphasising building triage for rescuer safety), and mass casualty non-medical triage could have measurable effects in reducing deaths and injuries and enhancing resilience.

Earthquakes themselves should be considered as definitive ‘early warning’ signs of aftershocks and precursors for tsunamis. Instructions to stay in bed during the shaking (the place least associated with injury), keep flashlight and shoes secured by the bed, exit carefully, do not re-enter damaged buildings, and avoid hazards outside are all supported by the evidence presented here.

3.10 Conclusions

The goals of earthquake epidemiology should not be limited to casualty estimation or fatality prevention. Providing an evidence basis for recommendations to the public for disaster risk reduction measures to be taken before earthquake onset as well as guidance for behaviour during the shaking and effective response should all be explicit outcomes of such research. It is equally the responsibility of casualty researchers to measure the impacts of the mitigation and preparedness measures most widely promoted.

A comprehensive and ongoing body of research requires that we study the impacts of many earthquakes that differ with respect to location, time, secondary hazards, changes in construction technology and the impact of household mitigation and community response-preparedness measures. Scientific sampling methods, and the use of standard classification schemes for building damage and injury typology are vital to producing credible and comparable findings. People can be trained ahead of time to more accurately identify building damage levels as well as confusing distinctions between injuries (e.g. bruises and crush injuries) by selecting from standard photographs.

The body of research presented provides a strong foundation for a clearer understanding of the most effective structural, non-structural, and behavioural measures that can be taken to mitigate the impacts of earthquakes. Future research will need to investigate the merits of specific protective actions and safer places that can be accessed during strong shaking. New issues to be addressed include concerns that multi-storey buildings will rain down highly dangerous non-structural building materials on those in the immediate vicinity of buildings, that in high-occupancy venues such as stadia and theatres, assuming the tucked brace position (as for an airplane crash) is advised rather than simply ‘drop, cover and hold’, and the extent to which orderly evacuation is practised is critical to life safety.

Chapter 4
Disaster Casualties – Accounting for Economic Impacts and Diurnal Variation

C. Scawthorn

Abstract While some progress is being made in the reduction of losses due to natural hazards such as earthquakes, more progress is needed. Casualty and economic loss trends for the twentieth century are first examined. As opposed to widely publicised claims of rapidly increasing loss trends, we find decreasing trends for both casualties and losses, when population growth and urbanisation are accounted for. In order to provide a single measure of the significance of disasters, the concept of Economic Adjusted Life Years (EALY) is introduced, which extends Disability Adjusted Life Years (DALY) as used in the health field to include economic costs of disasters. EALYs are calculated for a number of major twentieth century earthquakes, finding that millions of years of human productivity have been lost in these events. This equates to, case-by-case, setting back a particular group years to decades in its development. Lastly, the temporal patterns of twentieth century earthquake fatalities are examined, finding a significant diurnal variation. That is, earthquakes that occur at night have relatively more fatalities than they would if they occurred in daylight. Without accounting for diurnal variation, mortality and morbidity estimates can be off by a factor of as much as ± 34%.

4.1 Introduction

Figure 4.1 is a graph by Munich Re, frequently cited to indicate the increasing trend of natural disasters. It shows insured losses (lighter, lower portion of each column, and the lower increasing trend line) and total economic losses (total column height, and upper increasing trend line) due to earthquakes, floods, wind and volcanic natural disasters, for the period 1950–2000. Both economic and insured losses are

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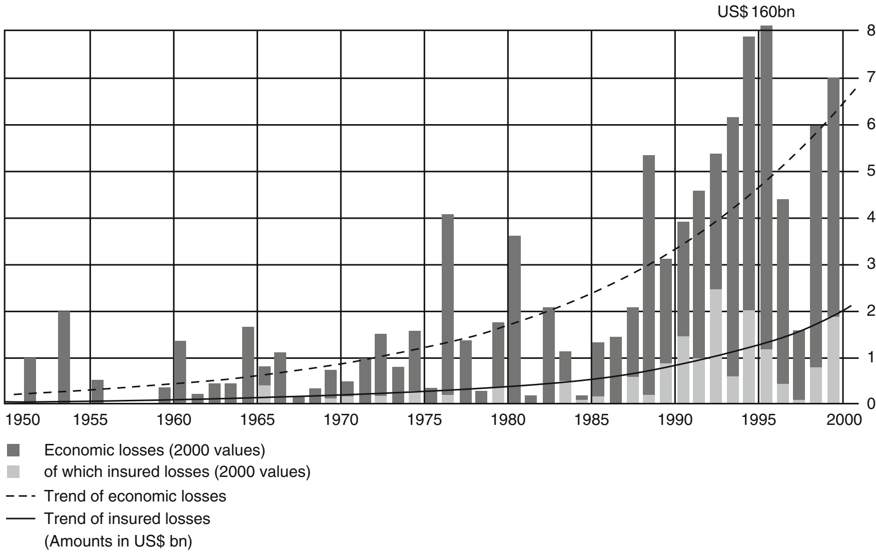


Fig. 4.1 Trend of worldwide economic and insured losses (Munich Reinsurance)

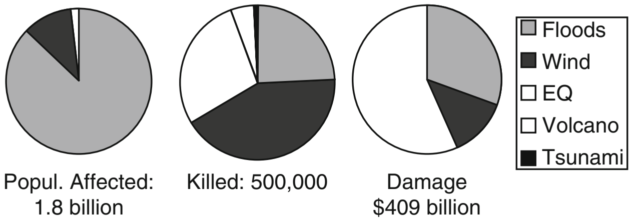


Fig. 4.2 Losses by disaster type 1985–1999 (EM-DAT; Damage normalised to $1999)

normalised to current (as of 2000) US dollars. The trend for both economic and insured losses is a dramatic increase in recent years.

However, Fig. 4.1 doesn't say anything about casualties. Figure 4.2 provides another perspective, in which it can be seen that floods affect most people, displacing a total of 1.8 million during the 15-year period 1985–1999 (selected as being relatively complete for the EM-DAT database). Windstorm accounts for a bit less than half the fatalities, with earthquake and windstorm about a quarter each, and earthquake accounts for a bit more than half of the total economic loss, which was about $409 billion ($1999).

In order to examine this trend in some more detail, for earthquakes, Munich Re data for the 15 most deadly earthquakes for the period 1900–2004 have been combined with several other, either very costly or deadly, events (1906 San Francisco, 1994 Northridge, 1995 Kobe, 2004 Niigata, Japan earthquakes, and 2004 Indian Ocean tsunami), as shown in Table 4.1.

Table 4.1 Selected large earthquake catastrophes (USGS, World Bank, Various)

Event	Year	Deaths	Econ. loss ($\$ \times 10^6$)
San Francisco	1906	2,000	524
Italy, Messina	1908	85,900	116
Italy, Avezzano	1915	32,600	25
China, Gansu	1920	235,000	25
Japan, Tokyo	1923	142,800	2,800
China, Gansu	1927	40,000	25
China, Kansu	1932	77,000	
Pakistan, Quetta	1935	50,000	25
Turkey, Erzincan	1939	32,900	20
Chile, Concepcion	1939	28,000	100
Peru, Chimbote	1970	67,000	550
China, Tangshan	1976	242,800	5,600
Guatemala	1976	23,000	1,100
Armenia, Spitak	1988	25,000	14,000
Iran, Gilan	1990	40,000	7,100
Northridge	1994	65	24,000
Japan, Kobe	1995	6,200	100,000
Turkey	1999	17,118	8,500
Taiwan	1999	2,297	
India, Bhuj	2001	20,085	2,100
Iran, Bam	2003	31,000	
Indonesia, Tsunami	2004	228,000	9,326
Pakistan, Kashmir	2005	86,000	5,200
Indonesia, Jogjakarta	2006	5,749	3,134
China, Wenchuan	2008	87,587	
Haiti	2010	222,521	

Actual deaths and economic losses (dollars at time of event) arising from these events are shown in Figs. 4.3 and 4.4. The trend over the last 100 years is that of decreasing deaths but increasing economic losses, even including the recent Indian Ocean tsunami mega-catastrophe.

It might be argued that these trends are due to ‘constant lives’ but ‘appreciated’ economic values. To examine these potential biases, Fig. 4.5 ‘normalises’ the data to current (as of year 2000) population densities, while Fig. 4.6 updates to economic losses to current (2000) dollars, and Fig. 4.7 updates economic losses to current (2000) dollars and ‘normalises’ the data to current (2000) population densities.

The ‘normalisation’ to current population densities is to account for population growth – a comparison of say actual 1906 earthquake fatalities versus a current event fails to account for today’s much greater populations at risk. Treating the data in this way shows that deaths still maintain a decreasing trend, of similar order of magnitude. This shows that improvements in construction, emergency response and medical treatment have truly saved lives.

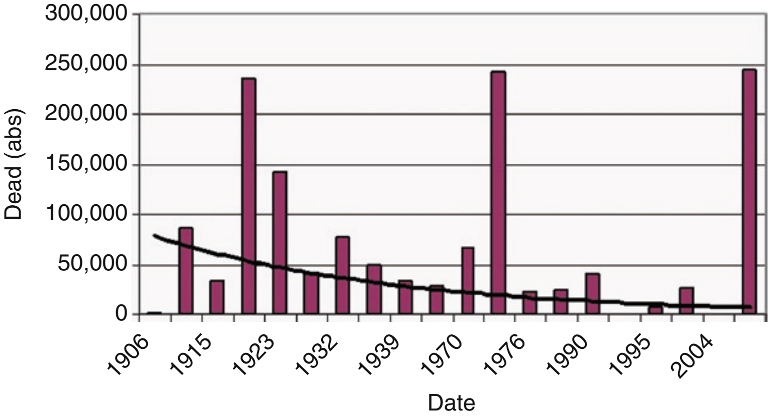


Fig. 4.3 Deaths for events shown in Table 4.1

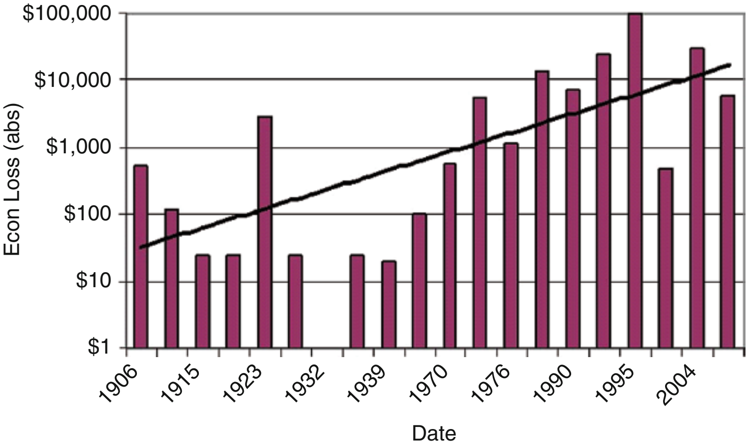


Fig. 4.4 Economic losses for events shown in Table 4.1

Economic losses still have an increasing trend, but the trend is significantly reduced – from a factor of 100 over about the 100-year period, to a factor of about 10 over the period, when only monetary appreciation is accounted for. If that and population growth is accounted for, however, the trend is seen to have a factor of about 2 over the period. That is, increasing population growth is a major factor in increasing earthquake catastrophes.

However, in recent decades population growth has been accompanied with another trend – that of urbanisation. Urbanisation – the concentration of people and economic value in large cities – tends to increase the volatility of natural hazards losses. By concentrating assets in cities, everything else being equal, more natural hazards such as earthquakes will occur in sparsely populated areas, with less loss. However, when an earthquake does occur in or near a heavily urbanised area, the 'direct hit' will be a much larger loss, compared with the pre-urbanisation situation

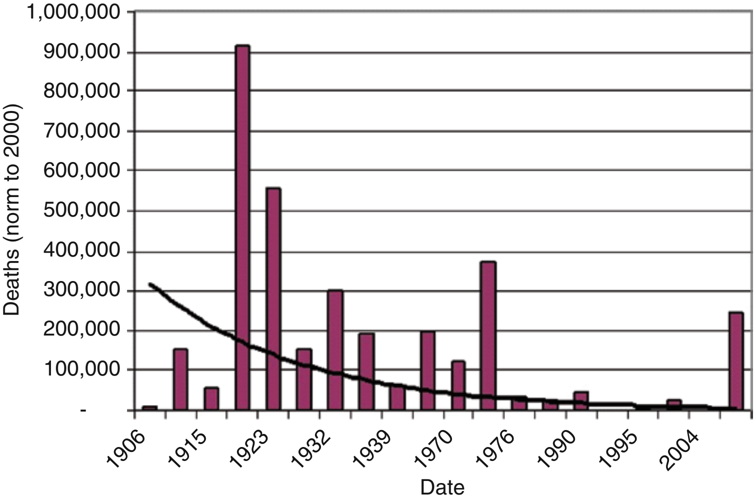


Fig. 4.5 Deaths for events shown in Table 4.1, 'normalised' to 2000 population densities

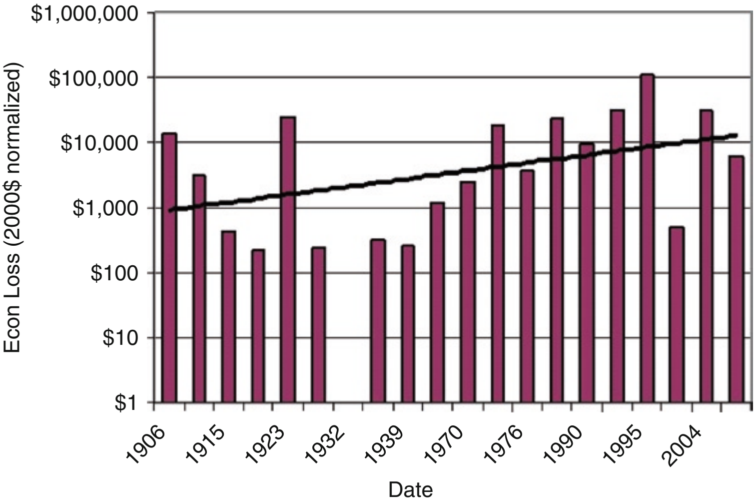


Fig. 4.6 Economic losses for Table 4.1 events, in $2000

of a more distributed population. The effect is fewer but larger catastrophes. To examine the effect of urbanisation on economic losses, Fig. 4.8 increases losses in earlier years by the ratio of average urbanisation in 2000, to the average urbanisation at the event time. That is, if 27% of the population were urban in 1950, and 57% in 2000, losses in 1950 are increased by 0.57/0.27 = 2.11 to account for the increases in losses that would have occurred had the same degree of urbanisation prevailed in 1950 as prevailed in 2000. Figure 4.8 shows a decreasing trend in losses with time, by a factor of about 2 over the period.

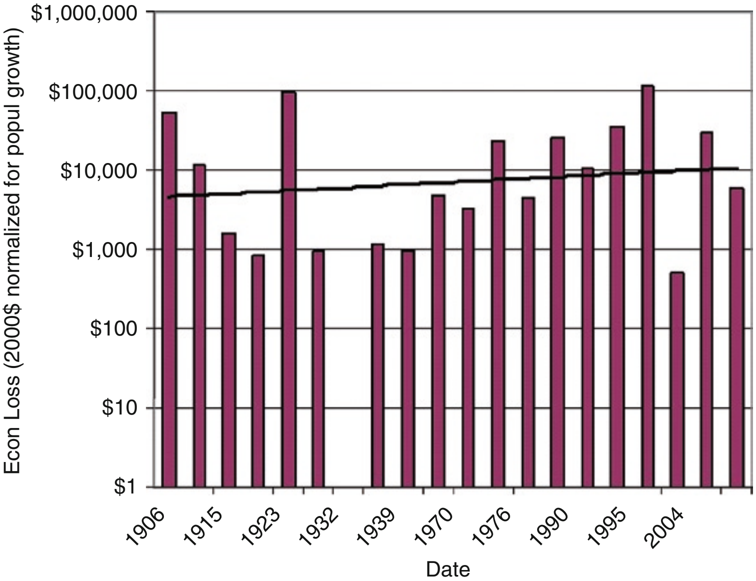


Fig. 4.7 Economic losses for events shown in Table 4.1, in $2000 and 'normalised' to 2000 population densities

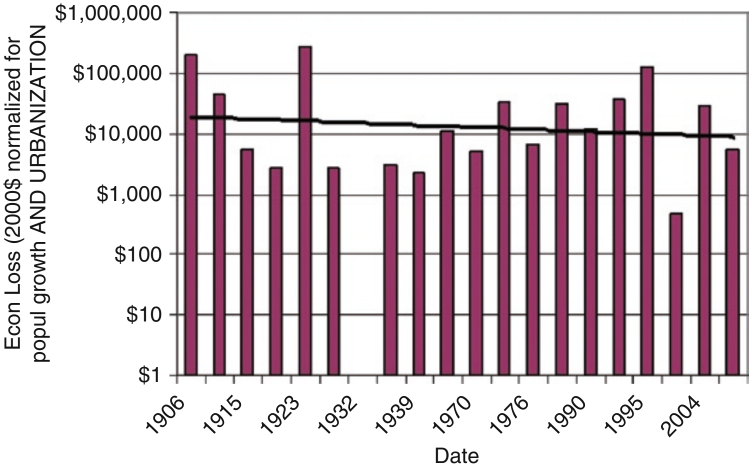


Fig. 4.8 Economic losses for events shown in Table 4.1, in $2000 and 'normalised' to 2000 population densities and urbanisation

4.2 Economic Adjusted Life Years (EALY)

In the discussion so far, deaths and economic impacts have been considered separately. In the disaster field, these two measures are typically separated, since equating or converting human lives to a monetary amount is considered problematic and involving insoluble issues of morality and equality. However, the health policy field has for some time employed an approach termed 'disability adjusted life years' (DALY) (World Bank 1993), which combine "time lived with a disability and the time lost due to premature mortality" (Homedes 2000).

Calculation of DALYs are based on five factors:

1. Duration of time lost due to a death at each age –based on the potential limit for life set at 82.5 years for women and 80 years for men.
2. Disability weights – the degree of incapacity associated with various health conditions. Values range from 0 (perfect health) to 1 (death).
3. Age-weighting function to consider relative importance of healthy life at different ages.
4. Discounting function which considers the value of health gains today compared to the value of health gains in the future.
5. Health is additive across individuals – two people each losing ten DALYs are treated as the same loss as one person losing 20 years.

In effect, "Years lost from premature mortality are estimated with respect to a standard expectation of life at each age. Years lived with disability are translated into an equivalent time loss by using a set of weights which reflect reduction in functional capacity, with higher weights corresponding to a greater reduction" (Anand and Hanson 1997). While not without controversy in the health policy field ((Anand and Jonson 1995), argue that the "concept is flawed and its assumptions and value judgements open to serious question"), DALYs have proven useful as a way to more accurately value the overall impacts of various health policy alternatives.

Herein, we define an analogous concept, which we term Economic Adjusted Life Years (EALY), in an effort to better value the overall impacts of a natural disaster. We define EALYs as:

$$\mathrm{EALY} = \mathrm{DALY} + \mathrm{EL} / \mathrm{W} \tag{4.1}$$

Where

EALY = Economic Adjusted Life Years

EL = non-recoverable economic loss

W = average annual wage per capita and

DALY is as defined in the medical field.

EALYs in effect extend the concept of DALYs (which measure the effective loss of total human temporal duration) to include the loss of human time input to capital creation. It does not equate human life to economic goods, but attempts to measure the amount of peoples' lives spent in economic activity, which has subsequently been destroyed by a disaster (the workers' lives were not lost, but what they spent their working lives doing, was destroyed).

In the results presented here, we approximated W by two times gross domestic product per capita, and for DALYs assume average duration of time lost due to a death is 40 years (and ignore time lost due to injuries). For example, if a disaster results in 1,000 lives lost, and $1 billion in economic loss, and the per capita gdp is $5,000, then

EALY = 40,000 + 100,000 = 140,000 lost years of economic productivity, which consists of 40,000 years lost due to human deaths (1,000 fatalities times 40 years of productivity per human) + 100,000 years lost due to destruction of property ($1 billion total divided by average annual wage per capita here approximated by twice $5,000 per capita GDP). If the affected population is 100,000, the EALY is equivalent to society (i.e., the population) having been set back 1.4 years of economic production.

Using this methodology, Fig. 4.9 shows EALYs for the events in Table 4.1, as adjusted for urbanisation. The trend is decreasing somewhat over the period, although the economic component (i.e., EL/W) is increasing over the period.

It is interesting to examine the EL/W component, adjusted for $2000 but otherwise not adjusted (e.g., for urbanisation). Figure 4.10 and Table 4.2 show this information, in which it can be seen that the heaviest toll was the 1988 Spitak event, due to the large economic loss factored with the low per capita gdp.

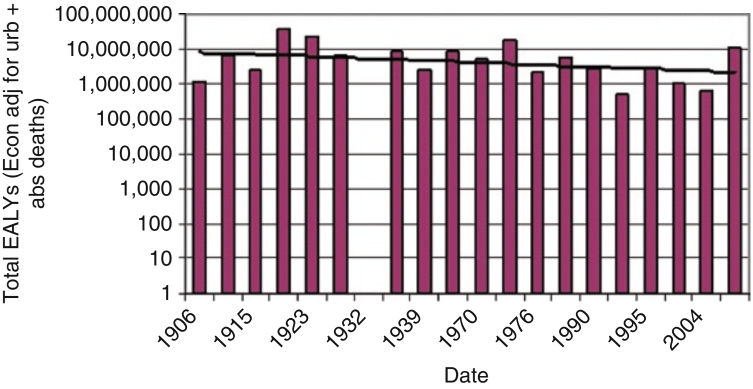


Fig. 4.9 EALYs for events shown in Table 4.1

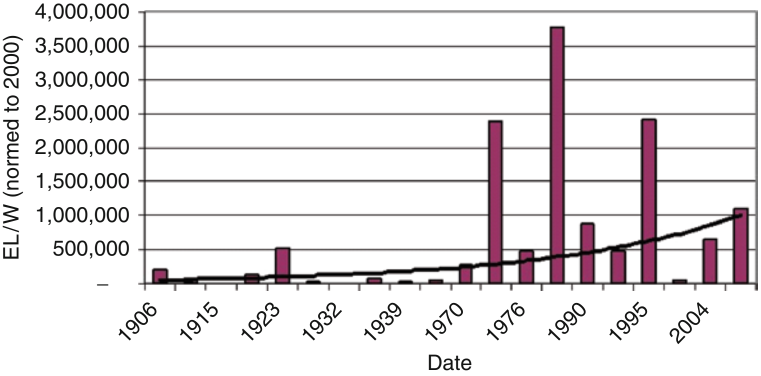


Fig. 4.10 EL/W for events in Table 4.1

Table 4.2 EALYs for selected large earthquakes

Event	Year	Econ loss ($ × 10^6) at time of event	EALY normed to $2,000
San Francisco	1906	524	207,015
Italy, Messina	1908	116	73,192
Italy, Avezzano	1915	25	9,934
China, Gansu	1920	25	133,821
Japan, Tokyo	1923	2,800	525,271
China, Gansu	1927	25	32,062
China, Kansu	1932		
Pakistan, Quetta	1935	25	77,878
Turkey, Erzincan	1939	20	19,908
Chile, Concepción	1939	100	50,806
Peru, Chimbote	1970	550	285,974
China, Tangshan	1976	5,600	2,384,807
Guatemala	1976	1,100	470,226
Armenia, Spitak	1988	14,000	3,783,491
Iran, Gilan province	1990	7,100	887,944
Northridge	1994	24,000	473,400
Kobe	1995	100,000	2,408,926
Iran, Bam	2003	500	47,195
Japan, Niigata	2004	30,000	643,777
Indian Ocean Tsunami	2004	6,000	1,111,111

There are a number of caveats to this work, primary of which is probably that the data on economic losses is extremely sparse, and of variable quality, as noted in NRC (Litan 1999). However, the overall trend at this time is decreasing life loss, and mildly increasing economic impacts on a per capital basis. The impacts differ widely depending on the economic development.

4.3 Twentieth Century Deaths and Diurnal Variation

Using the NOAA Significant Earthquakes database, Fig. 4.11 shows earthquake deaths during the twentieth C. by decade, while Fig. 4.12 shows their geographic distribution, quite different from total seismicity (as one would expect).

A dataset similar to NOAA and EM-DAT, of twentieth century earthquake loss data, was compiled by the author in the late 1970s (Scawthorn et al. 1978), from which one finding was a diurnal distribution of earthquake fatalities, Fig. 4.13.

That analysis is repeated here, with a more complete dataset. First, we examine whether there is any diurnal variation in earthquake occurrence, Fig. 4.14, and see there is virtually none.

Next, we examine total fatalities binned per hour of the day, where hour of the day (termed LTIM in the 1978 analysis) is the longitude adjusted time of the event, Fig. 4.15.

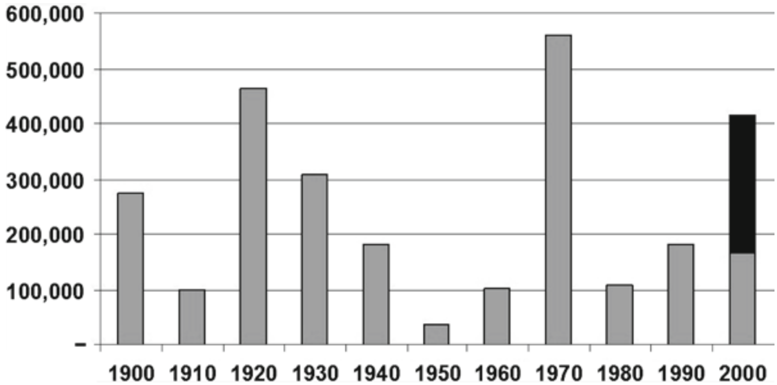


Fig. 4.11 Twentieth century earthquake deaths (total without tsunami 2.47 million) (*black column* shows the 2004 Indian Ocean tsunami deaths) (NOAA Significant Earthquakes Database)

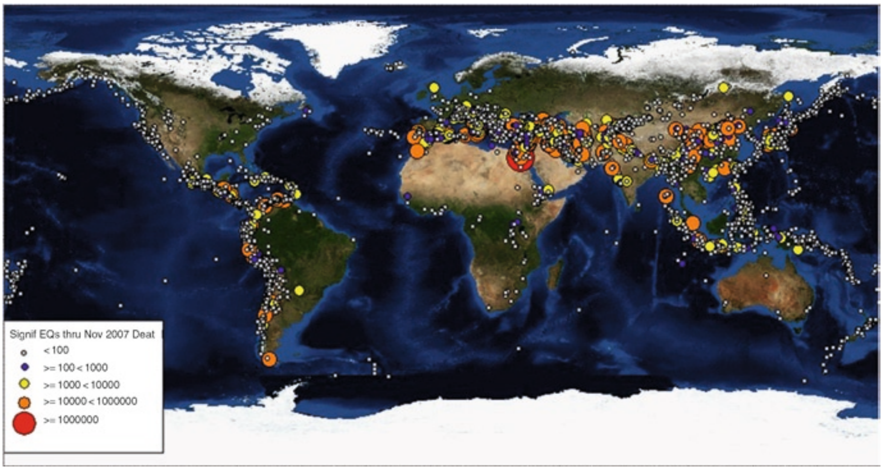


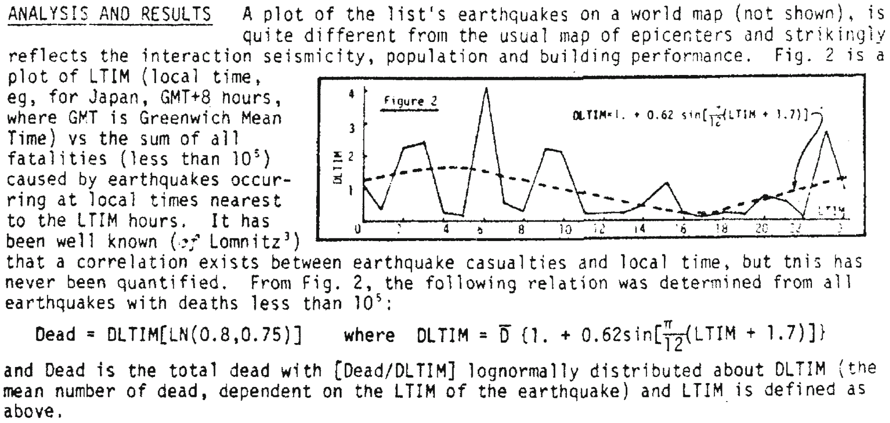
Fig. 4.12 Significant earthquake fatalities 2150BC to present

Next we adjust the hour for the length of daylight, based on date and latitude, Fig. 4.16.

As noted in the 1978 analysis, there appears to be some variation of fatalities, shifted away from daylight hours. To assess this, the data shown in Fig. 4.16 were normalised and regressed against a sine wave, as shown in Fig. 4.17.

The best fit sine wave is found to be (r = 0.38, N = 24):

$$F_d = F_m\left[1 + 0.34\sin\left(\frac{\tau}{12}(T + 3.3)\right)\right] \tag{4.2}$$



ANALYSIS AND RESULTS A plot of the list's earthquakes on a world map (not shown), is quite different from the usual map of epicenters and strikingly reflects the interaction seismicity, population and building performance. Fig. 2 is a plot of LTIM (local time, eg, for Japan, GMT+8 hours, where GMT is Greenwich Mean Time) vs the sum of all fatalities (less than 10^5) caused by earthquakes occurring at local times nearest to the LTIM hours. It has been well known (cf Lomnitz[3]) that a correlation exists between earthquake casualties and local time, but this has never been quantified. From Fig. 2, the following relation was determined from all earthquakes with deaths less than 10^5:

$$\text{Dead} = \text{DLTIM}[\text{LN}(0.8,0.75)] \quad \text{where} \quad \text{DLTIM} = \bar{D}\,\{1. + 0.62\sin[\tfrac{\pi}{12}(\text{LTIM} + 1.7)]\}$$

and Dead is the total dead with [Dead/DLTIM] lognormally distributed about DLTIM (the mean number of dead, dependent on the LTIM of the earthquake) and LTIM is defined as above.

Fig. 4.13 Diurnal distribution of earthquake fatalities (Scawthorn et al. 1978)

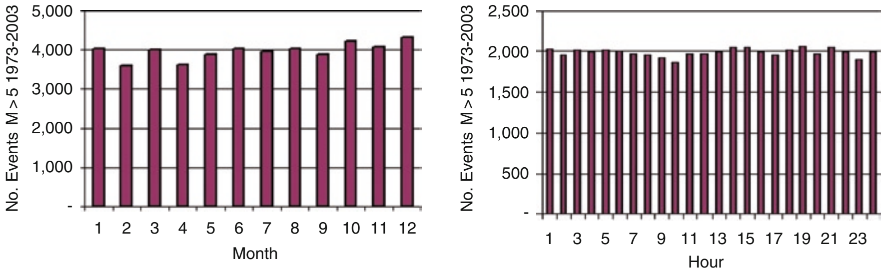


Fig. 4.14 Temporal variation of global seismicity, M ≥ 5, 1973–2003

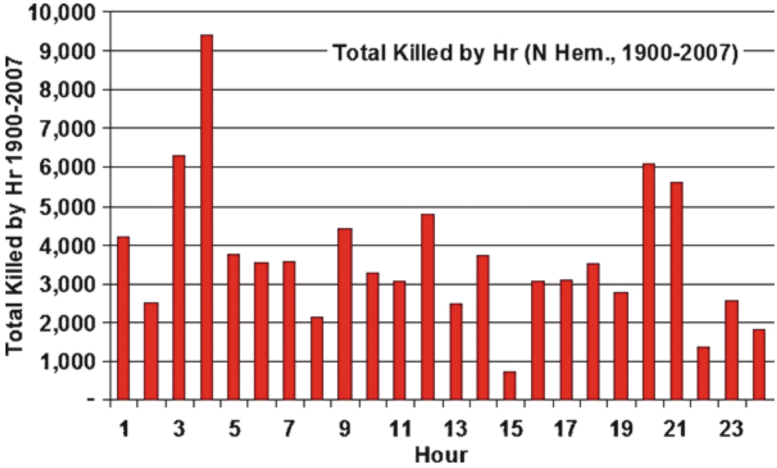


Fig. 4.15 Total killed by hour of the day (northern hemisphere only, 1900–2007)

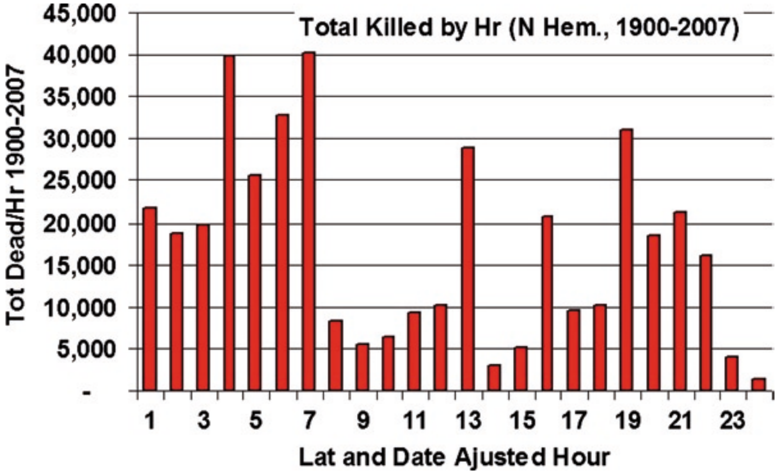


Fig. 4.16 Total killed by hour of the day, adjusted for length of daylight (northern hemisphere only, 1900–2007)

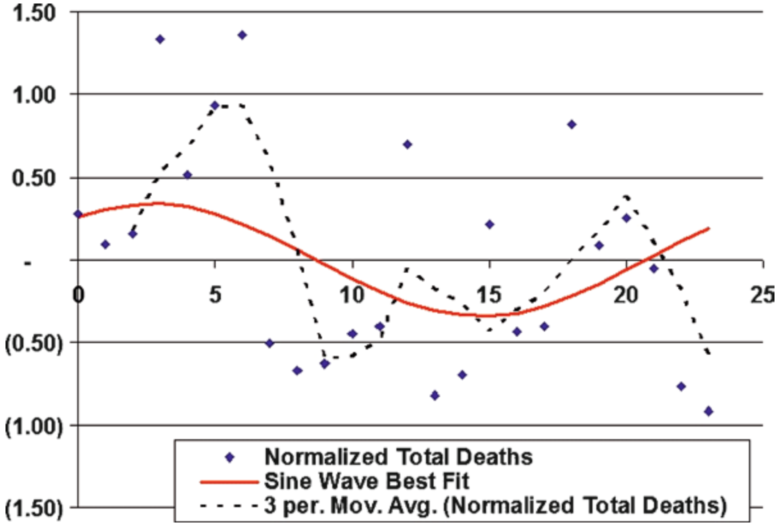


Fig. 4.17 Normalised fatalities with moving average and best fit sine wave

Where

F_d = Factor for fatalities accounting for diurnal variation

F_m = Mean fatalities, estimated not considering diurnal variation

T = Time of day, normalized to an equinox (i.e., considering length of daylight)

That is, it may be inferred that most fatalities have historically occurred in regions of low strength masonry, as seen in Fig. 4.12, and that fatalities are likely to be higher when people are caught unawares while sleeping, and therefore do not quickly evacuate their high collapse potential dwellings.

Compared with the 1978 analysis, the parameters T and LTIM are different, and the constants in the best fit sine waves are different, but the finding is basically the same. The conclusion is that, without accounting for diurnal variation, mortality and morbidity estimates can be off by a factor of as much as ± 34%.

Chapter 5
A Global Earthquake Building Damage and Casualty Database

R. Spence, E. So, S. Jenkins, A. Coburn, and S. Ruffle

Abstract This chapter presents a preliminary overview of the Cambridge University Earthquake Damage Database (CUEDD) now the Cambridge Earthquake Impact Database (CEQID) with emphasis on its human casualty component. CUEDD is based on earthquake damage data assembled by the Martin Centre at Cambridge University since 1980, complemented by other more-recently published and some unpublished data. The database through its organised, expandable and web-accessible format, summarizes information on worldwide post-earthquake building damage surveys which have been carried out since the 1960s (www.ceqid.org). Currently it contains data on the performance of more than 1.3 million individual buildings, in 600 surveys following 50 separate earthquakes. The database provides total recorded casualties (deaths, seriously and moderately injured), and casualty rates as a proportion of population with definitions of injury levels used, and information on dominant types of injury, age groups affected, etc. It also provides geographically disaggregated data where possible, and associates them with tables and GIS maps. Sources of information on other aspects of human casualty information (epidemiological studies, health care impacts, etc.) are provided. Analytical tools enable relationships between casualty rates, building classes and ground motion parameters to be determined.

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5.1 Introduction: Cambridge University Earthquake Damage Database

To improve the performance of buildings and other structures in earthquakes, it is essential, in addition to analytical and experimental studies, to observe performance of structures in real earthquakes. Only by such observations can we gain confidence that structural design is achieving its aim of providing adequate safety. In addition, the causes of the failure of specific aspects of structural designs can be identified by field observations, and the lessons learnt during past earthquakes could potentially help engineers to rectify them. Earthquake damage observations and damage surveys are also of crucial importance to assess vulnerability of existing buildings, for application in risk modelling for insurance or for urban mitigation planning.

However, collecting damage and loss data in the aftermath of a large earthquake presents significant challenges. Large earthquakes are rare and may cause devastating effects depending upon where they occur, which makes it vital to get the maximum amount of data from such events. Moreover, the window of opportunity to collect such data is very limited, as the demolition of damaged structures usually begins almost immediately after the event; while it takes time to organise and assemble a team with the skills needed to perform engineering assessments of causes of earthquake damage and also to compile the damage observations.

In spite of these challenges, many damage surveys have already been carried out in the past, some of them by international teams of experts for example, Earthquake Engineering Research Institute (EERI) from USA, Earthquake Engineering Field Investigation Team (EEFIT) group in the UK, and some of them by local country-specific teams of professionals. Much of the data are available in publications of one sort or another, though some remain in the archives of government departments or insurance companies. But for best analytical use to be made of the data it is essential to bring the data together and make this accessible to the research community, to enable cross-event analysis to take place, and to ensure that lessons learnt in one country or region can be applied elsewhere.

The Cambridge University Centre for Risk in the Built Environment (CURBE) has been involved in post-earthquake reconnaissance missions for over 25 years through the EEFIT UK group (www.eefit.org), and has assembled documents recording damage surveys (its own and those of others) throughout this time. But until now there has been no readily accessible form or medium through which the collected data-cum-observations can be archived electronically using a consistent format and also to facilitate its application at wider scale. Historically the data were made available through the mission-specific publication reports and through the research articles that discuss the observed vulnerability of selected building classes (e.g. Spence et al. 2008). However with the advent of new tools that allow the creation and design of web-accessible data architecture, a much wider accessibility of the data is now possible. Moreover, the publication in 2009 of the USGS ShakeMap archive (http://earthquake.usgs.gov/shakemap/), provides an estimate of the ground shaking at any location in any past event. This enables cross-event analyses against a consistent set of estimated ground motions and their variable impacts for the first time. The Cambridge

University Earthquake Damage Database (CUEDD) now the Cambridge Earthquake Impact Database (CEQID) has now been designed and assembled to take advantage of these new tools as discussed in subsequent sections.

This paper presents a preliminary overview of the CUEDD. CUEDD is based on earthquake damage data assembled by the Martin Centre at Cambridge University since 1980, complemented by other more recently published and some unpublished data. The database assembles the data pertaining to the worldwide post-earthquake building damage surveys which have been carried out since the 1960s into a single, organised, expandable and web-accessible format, with a direct access to event-specific shaking hazard maps. Analytical tools are available which enable cross-event relationships between casualty rates, building classes and ground motion parameters to be determined. This paper explains how these analytical tools work, and gives examples of the vulnerability data which can be derived from them. The Database is accessible to all users, and uses a simple XML format suitable for data mining. Location maps and images of damage are provided for each earthquake event. The Database links to the USGS ShakeMap archive to add data on local intensities and on measured ground shaking.

Currently the Database contains data on the performance of more than 1.3 million individual buildings, in over 600 surveys following 51 separate earthquakes, and the total is continuously increasing. The database also has a casualty element, which gives total recorded casualties (deaths, seriously and moderately injured), and casualty rates as a proportion of population with definitions of injury levels used, and information on dominant types of injury, age groups affected, etc. Table 5.1 shows the list of events covered at October 2009. Of the 51 events in the database, 23 were in Asia and the Pacific (12 of which were in Japan), 17 in Europe, Turkey and North Africa, and 11 in North or South America. Most of the surveys have been done in events since 1990; among these 51 events, 18 were prior to 1990, 21 between 1990 and 2000, and 14 since 2000. Of the 1.3 million buildings in the database, 0.45 million do not have a well-defined building or structural typology given; of the remainder, 78% are of timber frame, 14% masonry, 5% reinforced concrete, and 3% are of other structural types. Thus, in spite of its size, the Database in its current state is patchy in global coverage, and in terms of building typologies. Further extension to overcome these deficiencies is essential.

5.2 Database Structure

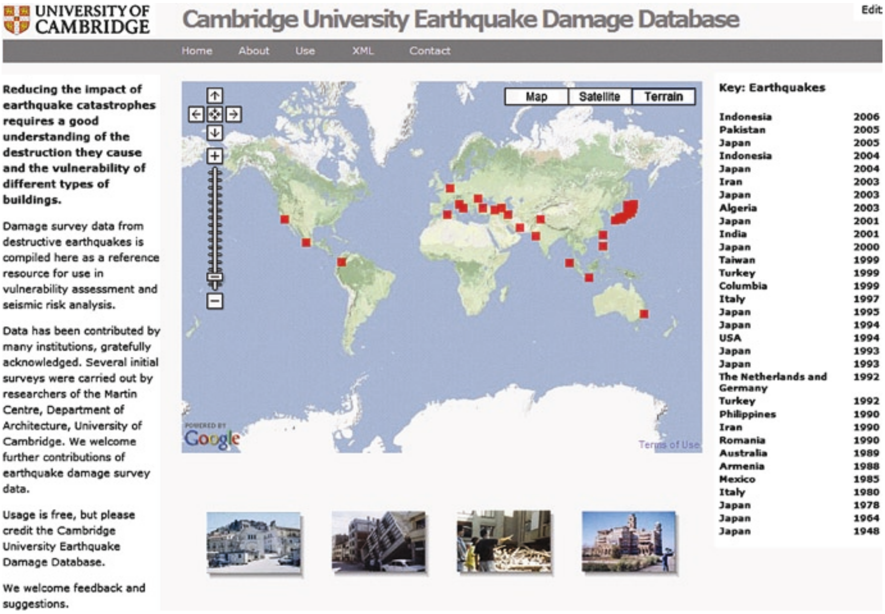
The Database is structured around four levels for web dissemination. At the top level the homepage (Fig. 5.1) shows a global map indicating epicentres of all earthquakes for which data are available, and lists the earthquakes by country and date. The website uses Google maps, which can be viewed at any desired scale, and viewed in three modes – road map, terrain map, or satellite image.

At the second level, by clicking on the earthquake name or location the primary event data for that earthquake becomes accessible (Fig. 5.2). This includes the data acquired from the USGS National Earthquake Information Center (NEIC) such as the date, time, magnitude, epicentral location, and the USGS ShakeMap ID.

Table 5.1 The events in the database in October 2009, by date and region

	Asia and Pacific		Americas		Europe, Turkey and North Africa	
Period	Date	Event	Date	Event	Date	Event
pre1970	28/06/1948	Japan (Fukui)	18/04/1906	USA (San Francisco)		
	16/06/1964	Japan (Niigata)	28/06/1925	USA (Santa Barbara)		
			10/03/1933	USA (Long Beach)		
			21/07/1952	USA (Kern County)		
			29/04/1965	USA (Puget Sound)		
1970–1989	23/05/1968	New Zealand (Inangahua)	09/02/1971	USA (San Fernando)	05/06/1976	Italy (Friuli)
	12/06/1978	Japan (Miyagi-Ken)	02/05/1983	USA (Coalinga)	20/06/1978	Greece (Thessaloniki)
	2/3/1987	New Zealand (Edgecombe)			15/04/1979	Montenegro
	27/12/1989	Australia (New castle)			23/11/1980	Italy (Irpina)
	27/07/1976	China (Tangshan)			13/09/1986	Greece (Kalamata)
					07/12/1988	Armenia (Spitak)
					29/10/1989	Algeria (Tipaza)
					30/05/1990	Romania
					16/07/1990	Phillippines
					13/12/1990	Italy (Eastern Sicliy)
1990–1999	20/06/1990	Iran (Manjil)	17/01/1994	USA (Northridge)	13/03/1992	Turkey (Erzincan)
	15/01/1993	Japan (Kushiro-oki)	25/01/1999	Colombia (Armenia)	13/04/1992	Germany (Roermond)
	30/09/1993	India (Maharashtra)			22/12/1992	Egypt (Cairo)
	12/07/1993	Japan (Hokkaido-Nansei-oki)			15/06/1995	Greece (Aighion)
	28/12/1994	Japan (Sanriku-Haruka-oki)			26/09/1997	Italy (Umbria-Marche)
	17/01/1995	Japan (Kobe)			26/03/1998	Italy (Umbria)
	21/09/1999	Taiwan (Chi-Chi)			09/09/1998	Italy (Pollino)
					17/08/1999	Turkey (Kocaeli)
					07/09/1999	Greece (Athens)

Since 2000	06/10/2000	Japan (Tottori-Ken Seibu)	15/08/2008	Peru (Pisco)	31/10/2002	Italy (Molise)
	26/01/2001	India (Gujarat)			21/05/2003	Algeria (Boumerdes)
	24/03/2001	Japan (Geiyo)			14/08/2003	Greece (Lefkada)
	25/07/2001	Japan (Miyagi-Ken-Hokubu)				
	26/12/2003	Iran (Bam)				
	23/10/2004	Japan (Chuetsu)				
	20/03/2005	Japan (Fukuoka-Ken-Seiho-oki)				
	08/10/2005	Pakistan (Kashmir)				
	26/05/2006	Indonesia (Yogyakarta)				
	12/05/2008	China (Wenchuan)				



Reducing the impact of earthquake catastrophes requires a good understanding of the destruction they cause and the vulnerability of different types of buildings.

Damage survey data from destructive earthquakes is compiled here as a reference resource for use in vulnerability assessment and seismic risk analysis.

Data has been contributed by many institutions, gratefully acknowledged. Several initial surveys were carried out by researchers of the Martin Centre, Department of Architecture, University of Cambridge. We welcome further contributions of earthquake damage survey data.

Usage is free, but please credit the Cambridge University Earthquake Damage Database.

We welcome feedback and suggestions.

Key: Earthquakes

Indonesia	2006
Pakistan	2005
Japan	2005
Indonesia	2004
Japan	2004
Iran	2003
Japan	2003
Algeria	2003
Japan	2001
India	2001
Japan	2000
Taiwan	1999
Turkey	1999
Columbia	1999
Italy	1997
Japan	1995
Japan	1994
USA	1994
Japan	1993
Japan	1993
The Netherlands and Germany	1992
Turkey	1992
Philippines	1990
Iran	1990
Romania	1990
Australia	1989
Armenia	1988
Mexico	1985
Italy	1980
Japan	1978
Japan	1964
Japan	1948

Fig. 5.1 CUEDD homepage

Earthquake
Italy 1980
Irpinia

Region
Irpinia (Campania, Basilicata)

Event Date (dd/mm/yyyy)
23/11/1980

Event time (local)
18:34

Time zone (+- hours)
1

Depth (Km)
6.9

Magnitude
6.9

Lat
40.788

Long
15.31

Lat/Long Accuracy
Medium

Secondary Effects

PDE Shaking Deaths
4900

USGSShakeMapID
198011231834

Irpinia 1980 Damage Studies

- Braga et al. Survey
- Coburn, Spence, et al.

Key: Earthquakes

China	2008
Indonesia	2006
Pakistan	2005
Japan	2005
Indonesia	2004
Japan	2004
Iran	2003
Greece	2003
Japan	2003
Algeria	2003
Japan	2001
India	2001
Japan	2000
Taiwan	1999
Greece	1999
Turkey	1999
Columbia	1999
Italy	1997
Greece	1995
Japan	1995
Japan	1994
USA	1994
Japan	1993
Japan	1993
The Netherlands and Germany	1992
Turkey	1992
Philippines	1990
Iran	1990
Romania	1990
Australia	1989
Algeria	1989
Armenia	1988
Greece	1986
Mexico	1985
Italy	1980
Japan	1978

Fig. 5.2 Damage database: event main page giving overall event characteristics

In addition, this level provides the event-specific record of the total number of casualties caused during an earthquake. At this level the web-portal also provides the list of separate damage and casualty studies that were available within the Database.

Further information can be accessed by clicking on to each of the studies listed as a part of the third level. This level is specific to a particular study (of damage or casualties) and it provides a range of information as illustrated in Figs. 5.3 and 5.4.

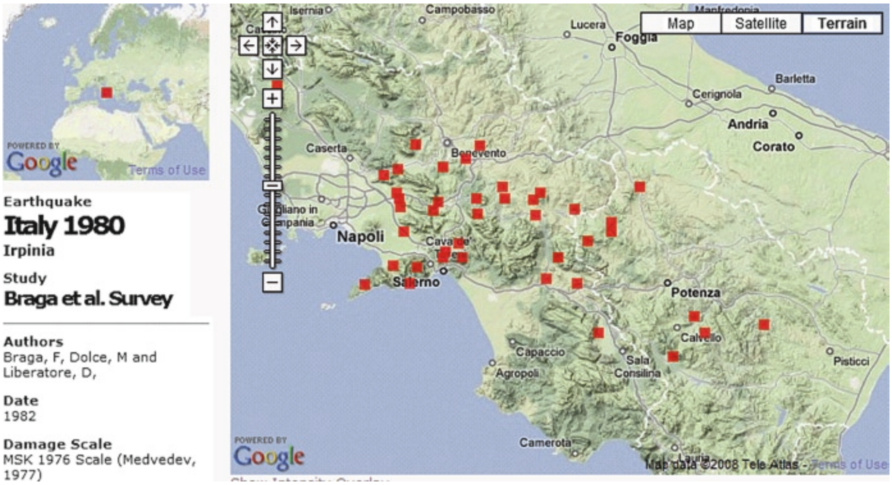

Earthquake
Italy 1980
Irpinia
Study
Braga et al. Survey
Authors
Braga, F, Dolce, M and Liberatore, D,
Date
1982
Damage Scale
MSK 1976 Scale (Medvedev, 1977)

Fig. 5.3 Typical map for a particular study, giving reference information, and map of study locations

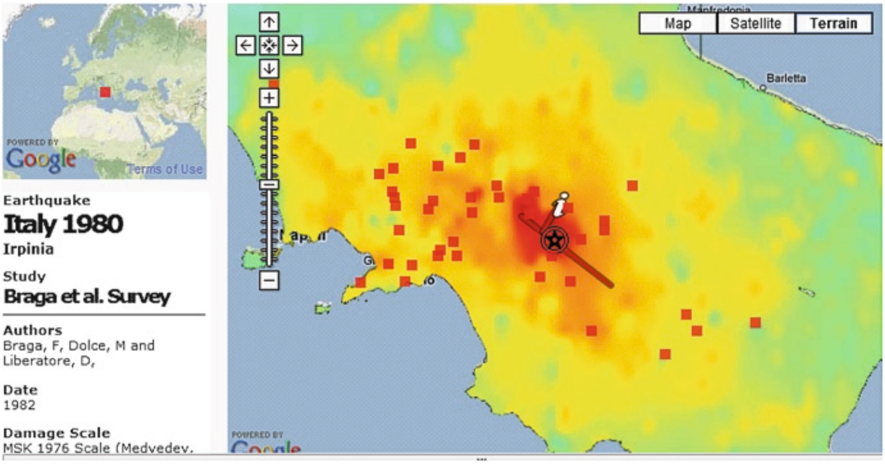

Earthquake
Italy 1980
Irpinia
Study
Braga et al. Survey
Authors
Braga, F, Dolce, M and Liberatore, D,
Date
1982
Damage Scale
MSK 1976 Scale (Medvedev,

Fig. 5.4 USGS ShakeMap overlay for the selected event shown in Fig. 5.3

For each study a map showing the locations of surveys carried out within that study is provided (Fig. 5.3) and the details of the damage level and building typology classification systems used during the survey (see Tables 5.2 and 5.3). The survey locations are also listed for quick assessment of geographic coverage of the study.

An overlay is available showing the USGS ShakeMap (Fig. 5.4) which can be contoured according to various measures of ground shaking intensity. Selected photographs (originally taken by the survey team) showing typical damage for that event are displayed. Documentation and reference material for the study is also provided.

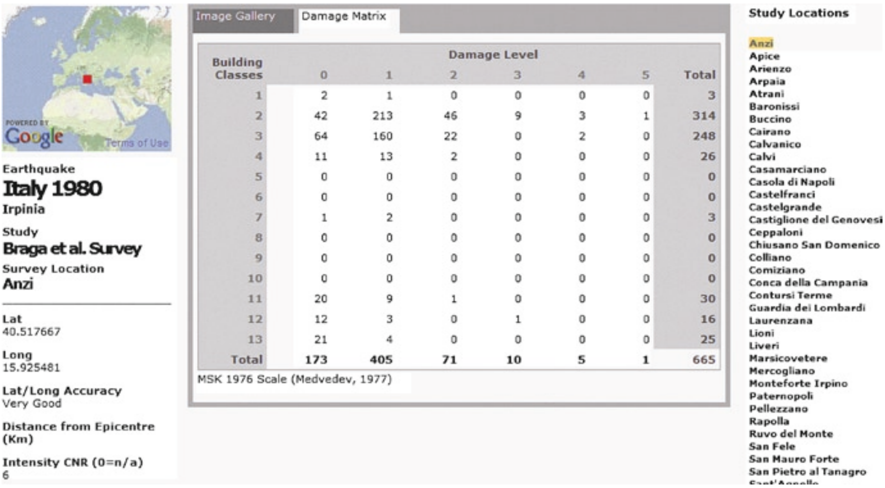
At the fourth (final) level is the detailed survey data for a particular location. Each survey is defined by a particular location, by a number of separate building classes and by the number of buildings suffering different levels of damage. It is

Table 5.2 Typical set of damage levels employed for a particular damage study

Damage levels	Damage	Description
D0	Undamaged	No visible damage
D1	Negligible to slight damage	Hairline cracks
D2	Moderate damage	Cracks 5–20 mm
D3	Substantial to heavy damage	Cracks > 20 mm or wall material dislodged
D4	Very heavy damage, partial collapse	Complete collapse of individual wall or roof support
D5	Total or near total collapse	More than one wall or more than half of the roof collapsed

Table 5.3 A typical sub-set of building classifications and descriptions

Building class	Description
Residential masonry built before 1920	Load-bearing masonry, mainly residential, 2–3 storeys built before 1920; some built eighteenth century and before.
Residential masonry built between 1920 and 1960	Load-bearing masonry, chiefly residential, 2–3 storeys, mostly post war c 1950s, some 1930s; no chimneys
Residential masonry built since 1960	Modern load-bearing masonry, chiefly residential; some cavity wall construction



Earthquake
Italy 1980
Irpinia

Study
Braga et al. Survey

Survey Location
Anzi

Lat
40.517667

Long
15.925481

Lat/Long Accuracy
Very Good

Distance from Epicentre (Km)

Intensity CNR (0=n/a)
6

Building Classes	Damage Level 0	1	2	3	4	5	Total
1	2	1	0	0	0	0	3
2	42	213	46	9	3	1	314
3	64	160	22	0	2	0	248
4	11	13	2	0	0	0	26
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	1	2	0	0	0	0	3
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
11	20	9	1	0	0	0	30
12	12	3	0	1	0	0	16
13	21	4	0	0	0	0	25
Total	173	405	71	10	5	1	665

MSK 1976 Scale (Medvedev, 1977)

Study Locations

- Anzi
- Apice
- Arienzo
- Arpaia
- Atrani
- Baronissi
- Buccino
- Cairano
- Calvanico
- Calvi
- Casamarciano
- Casola di Napoli
- Castelfranci
- Castelgrande
- Castiglione del Genovesi
- Ceppaloni
- Chiusano San Domenico
- Colliano
- Comiziano
- Conca della Campania
- Contursi Terme
- Guardia dei Lombardi
- Laurenzana
- Lioni
- Liveri
- Marsicovetere
- Mercogliano
- Monteforte Irpino
- Paternopoli
- Pellezzano
- Rapolla
- Ruvo del Monte
- San Fele
- San Mauro Forte
- San Pietro al Tanagro

Fig. 5.5 The damage data for a typical earthquake study location presented in tabular form showing numbers of buildings or as a fraction of total building stock (Fig. 5.5). The latitude and longitude of the location (and an indication of its accuracy) and the observed or calculated ground shaking at that location are also shown. A small map provides a link to the location. The survey data is accompanied by a strip of captioned images showing examples of the damage at that location. These can be expanded full screen.

5.3 The Casualty Data

In addition to physical damage surveys from past earthquakes, the Database also houses casualty information for some events. The difficulties in finding useful and dependable data from past research and literature have prompted the development of this casualty database which would promote:

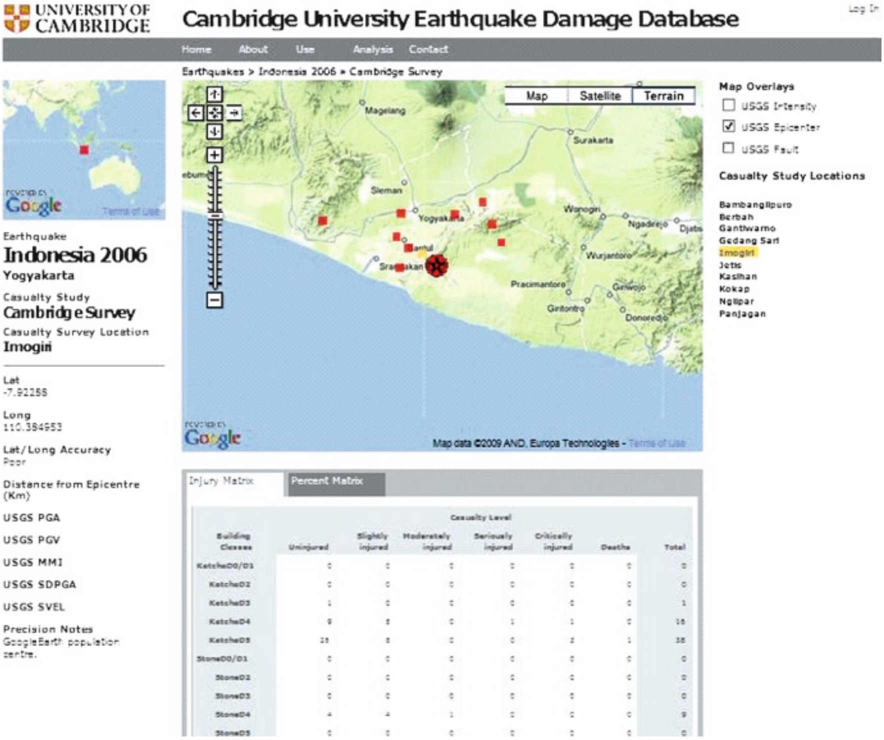
- Sharing of knowledge on earthquake casualties from previous events
- Translations of research from the local language into a common language whether mathematical or prose in English
- Peer review of posted information
- Development of global casualty estimation models
- Development of guidelines in collecting such information after earthquakes amongst disciplines
- Standardisation of injury definitions

Despite the differences in the nature of events and the difficulty in conforming individual events to averages, there have been significant recent events which have informed us of the ways earthquake ground motions have affected their local inhabitants. Each event has its own characteristics in terms of amplitude of ground shaking and its spatial distribution, local time of earthquake occurrence, proximity of population to severe ground shaking and presence or absence of vulnerable housing stock and human behaviour during an earthquake. Although there are many factors affecting the scale and therefore impact on humans, it is nonetheless essential to learn from these earthquakes in order to understand the degree in which each variable affects the final casualty toll.

In the same format as shown for the damage data, casualty studies for events appear in the event page (Fig. 5.2). At the fourth (final) level, casualty data are presented in the form of regional information, where fatalities and injuries are given for affected districts, towns and villages. The locations of these individual studies are shown as the population centres of the study areas with corresponding intensities taken from USGS ShakeMaps.

If casualty surveys are available, where fatalities and injuries are related to housing types and damage to housing types, the matrix is further divided into rows according to injury levels, as shown in Fig. 5.6.

For each event, the Database also houses miscellaneous information such as published casualty literature which includes casualty models for the country or region and published fatality functions and casualty relationships. Since published models



Cambridge University Earthquake Damage Database

Earthquakes > Indonesia 2006 » Cambridge Survey

Earthquake
Indonesia 2006
Yogyakarta
Casualty Study
Cambridge Survey
Casualty Survey Location
Imogiri

Lat
-7.92258

Long
110.384953

Lat/Long Accuracy
Poor

Distance from Epicentre (Km)

USGS PGA

USGS PGV

USGS MMI

USGS SDPGA

USGS SVEL

Precision Notes
GoogleEarth population centre.

Map Overlays
☐ USGS Intensity
☑ USGS Epicenter
☐ USGS Fault

Casualty Study Locations

Bambanglipuro
Berbah
Ganthwarno
Gedang Sari
Imogiri
Jetis
Kasihan
Kokap
Ngllpar
Panjagan

	Casualty Level						
Building Classes	Uninjured	Slightly injured	Moderately injured	Seriously injured	Critically injured	Deaths	Total
KetcheD0/D1	0	0	0	0	0	0	0
KetcheD2	0	0	0	0	0	0	0
KetcheD3	1	0	0	0	0	0	1
KetcheD4	9	5	0	1	1	0	16
KetcheD5	25	8	0	0	2	1	36
StoneD0/D1	0	0	0	0	0	0	0
StoneD2	0	0	0	0	0	0	0
StoneD3	0	0	0	0	0	0	0
StoneD4	4	4	1	0	0	0	9
StoneD5	0	0	0	0	0	0	0

Fig. 5.6 Casualty data from the Cambridge survey of the Yogyakarta earthquake of 2006, broken down into damage and injury levels

relate deaths and most injuries to building damage, damage forms the focus of the Database. In most loss estimation models, casualty rates are presented as a percentage of occupants in a particular building at the time of the earthquake. However, when evaluating the available literature, it was found that many studies do not necessarily have statistics in this form. A decision was therefore made to present the data in two forms. The original data are kept in their entirety but where there can be inferences made on population and occupancy rates based on supplementary local knowledge of the earthquake, a postulated set of casualty rates are calculated for comparison purposes. An example of this is shown in Fig. 5.7 for the 1999 Kocaeli event where the data obtained from Petal's (2004) field study are compared against published rates from HAZUS (NIBS and FEMA 2003), ATC-13 and Erdik (2001).

One of the aims of the casualty component of CUEDD is to bring together practitioners from different disciplines involved in earthquake emergency management. In line with this, the Database also houses medical and public health information from past earthquakes including studies on medical causes of deaths and injuries. An analysis of this information may tell us more about the types of injuries associated with different housing, climatic and cultural environments. For example, none of the 1,502 patients received at the Pakistani military hospital surveyed by Mulvey et al. (2008) were identified as having either crush injuries or acute renal failure in the first

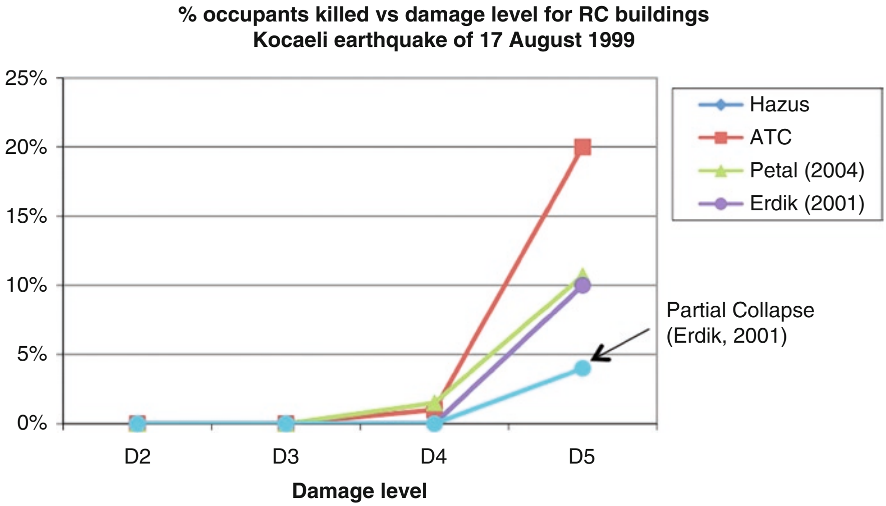


Fig. 5.7 Kocaeli earthquake of 17 August 1999; graph comparing percentage of occupants killed in reinforced concrete housing from a survey in Gölcük and rates published by various sources

72 h after the Kashmir earthquake. This compares to 17% of incidences found in the Kocaeli earthquake (Bulut et al. 2005) and 2–5% suggested for major earthquakes (Sheng 1987). The lack of crush injury cases may be due to the high mortality rate from the heavy masonry structures or an indication of the failure of the road network bringing rescuers into the affected area of Kashmir. In addition, only 73% of the surveyed patients reviewed continued with medical follow-ups which the authors say could be an indication of cultural beliefs. These pieces of information could be invaluable for international medical units in training for international disaster deployments.

As more information is gathered from future earthquakes, the casualty database will provide a good reference for comparative studies. Differences in the casualty ratios from one event to another may be partly explained by variations in building quality, but also by other hazards and causes.

5.4 Analytical Tools

The damage data assembled in CUEDD are derived from a wide range of damage surveys in many different countries, and conducted for different purposes; not surprisingly many different approaches are used both for classifying the types of buildings and structures affected, and also for defining the damage levels. If these data are to be used to build useful indicators of vulnerability using cross-event analysis, a means to organise the data into a smaller number of generic classes, both of building types and of damage levels is needed. However, different users may want to assemble different groups of structures, and may not all have the same view of which of the survey-defined classes should be grouped together. The analytical tools developed in CUEDD are designed so that this can be achieved by the user of the Database, providing the maximum flexibility in defining the analyses to be used.

Data are in XML format and can be downloaded using specified URLs and read into Excel or used directly in software applications. The following six data files are available:

- List of earthquakes and their characteristics
- List of separate studies and their key data
- List of survey locations and their characteristics
- List of all damage levels defined and equivalent master damage levels assumed
- List of all building classes defined
- Raw damage data

Using these XML files, survey data can be selected across events by building class, ground shaking level, and damage level, and criteria such as "greater than" a given damage level selected. "Superclasses" can be user-defined to assemble damage data across studies using different classifications. One particular set of building typology superclasses is shown in Table 5.4. Damage data from particular regions or time-periods can be assembled as needed.

Two examples of analytical results are given, from the damage and casualty parts of the Database. The first example is a cross-event damage analysis to derive empirical vulnerability curves for load-bearing masonry (Superclass M2, see Table 5.4), damage states vs. MMI (Modified Mercalli Intensity). Curves are based on data from 199 worldwide damage surveys, including 40,000 buildings. Since the dataset chosen for analysis is worldwide a high level of uncertainty can be expected. However, there was still insufficient data at MMI = 5 or MMI = 10 for values to be found for these intensity levels. For intensities MMI = 6 to 9 Fig. 5.8 shows average values of % exceeding each damage level D1 to D5, and regression curves assuming a cumulative normal

Table 5.4 Example of user-defined "superclasses"

Construction typology		Superclass category	
M	Masonry	M1	Weak masonry
		M2	Brick and block masonry, no rc slab
		M3	Brick and block masonry with rc slab
		M4	Reinforced or confined masonry
RC	Reinforced concrete	RC1L	RC pre code, low rise
		RC1M	RC precode, mid or high rise
		RC2L	RC early code, low rise
		RC2M	RC early code, mid or high rise
		RC3L	RC advanced code, low rise
		RC3M	RC advanced code, mid or high rise
		RCSW	RC shear wall
T	Timber	TH	Heavy timber frame
		TL	Light timber frame
S	Steel	SMF	Steel moment frame
		SBF	Steel braced frame
		SLF	Light steel frame

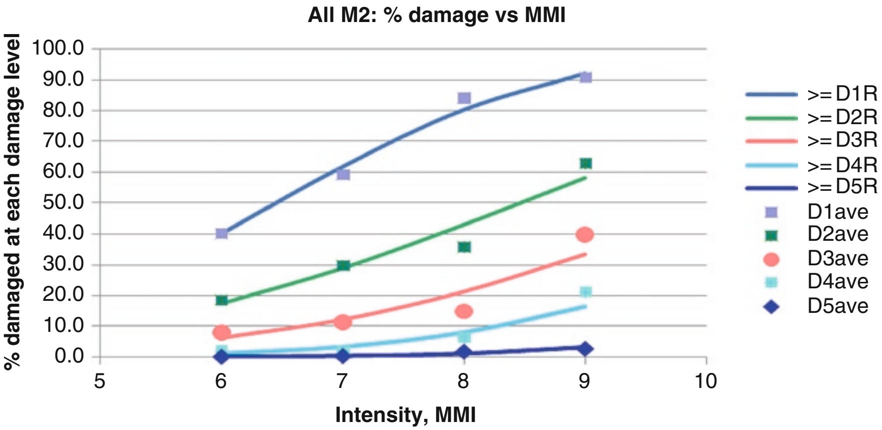


Fig. 5.8 Percentage exceedence curves vs. MMI for M2 superclass

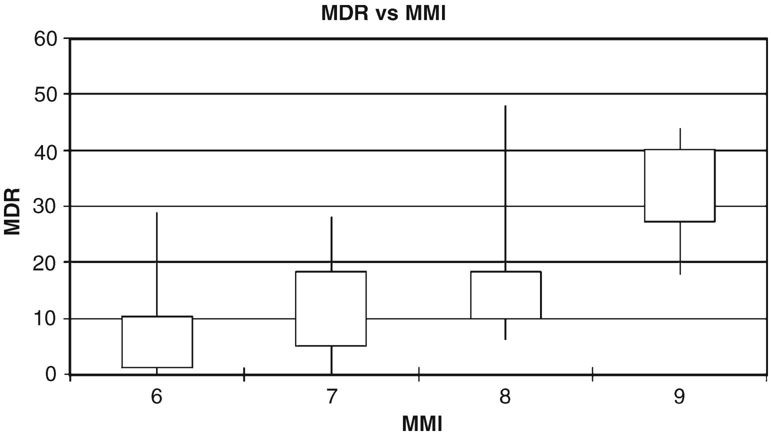


Fig. 5.9 Mean and range of MDR vs. MMI for M2 superclass

distribution against MMI intensity. Figure 5.9 shows a box and whiskers plot of mean damage ratio (MDR) vs. MMI. Here the mean damage ratio may be calculated from the raw damage data by assigning a damage ratio to each damage level; these damage ratios are also user-definable. Such plots can be drawn for any chosen measure of ground motion.

Figure 5.10 shows a comparison between the mean damage ratio (MDR) values derived from this analysis with the mean value derived from an earlier analysis done as part of the GEVES project which includes vulnerability curves derived from a variety of sources (Spence et al. 2008). Estimated MDR at lower intensities is significantly higher using the analysis from CUEDD, while that at higher intensities MDR is somewhat lower. The use of MMI intensities derived from the empirical ground motion prediction equations used in the development of the USGS ShakeMap rather than locally derived intensities may be partly responsible for these differences, but further analysis is needed to evaluate their significance.

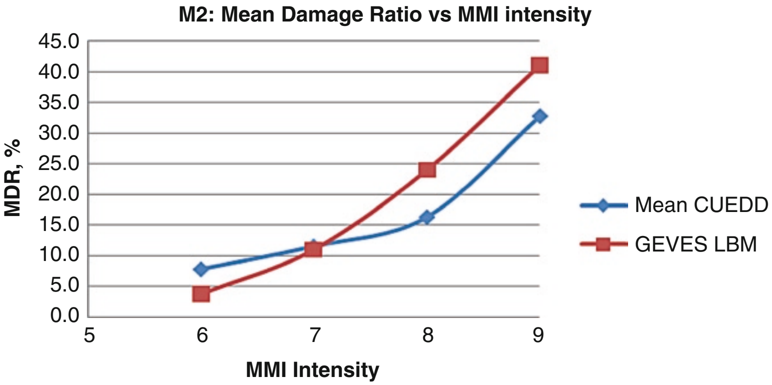


Fig. 5.10 Comparison of empirical with GEVES vulnerability curves for class M2

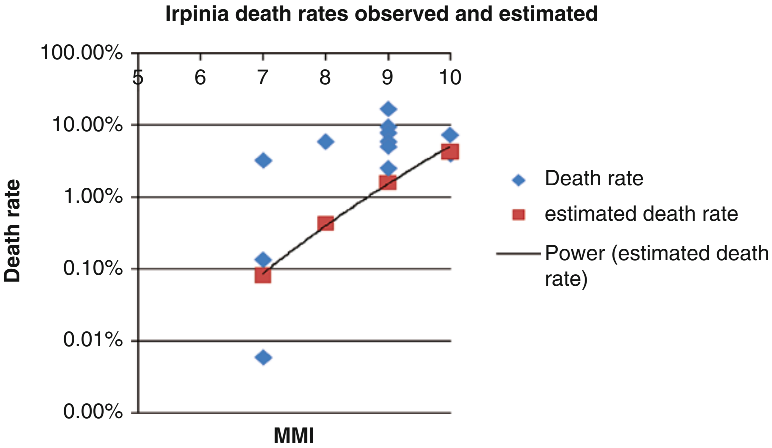


Fig. 5.11 Observed and estimated death rates by MMI intensity in the 1980 Irpinia earthquake

A second application of CUEDD was its use to compare observed and estimated fatality rates for a number of events for which fatality data was available on a geographically distributed basis, by village or district, and is currently available in CUEDD. For each event a USGS ShakeMap was available, providing the opportunity to obtain ground shaking data for each location. And for each location a total population affected was available, enabling a fatality rate to be determined for each location, and aggregated across all locations. For each event, the reported fatality rate for each location was plotted against USGS ShakeMap intensity, as determined from the lat-long coordinates at that location; this was compared with an estimated fatality rate plotted as a continuous function of intensity, using the process described elsewhere (So and Spence 2009). An example of the comparative plots is shown in Fig. 5.11, for the 1980 Irpinia earthquake in Southern Italy, for which casualty rates were available for 11 municipalities. These plots indicate that there is a wide scatter of fatality rates, but nevertheless for all events there is a tendency to higher fatality rates at higher intensities, as would be expected; and, for all the events plotted, the estimated fatality rates are within the plotted data points.

5.5 Conclusions

Although individual events do not conform to averages these earthquake damage and casualty statistics and correlations developed for specific events do provide a basis for probabilistic reporting of the likelihood of damage and casualties in specific regions. A collation of available field data will help validate predictions in loss estimation models. Collecting information including observational field data on the damage levels sustained at various ground motions and the associated casualties will help form empirical vulnerability relationships, which are needed especially in developing regions where there is little known of the structural properties and seismic resistance of local building types.

A careful study of earthquake damage, casualty statistics and field surveys over the past 30 years has allowed this compilation of information. In an attempt to standardise the method of recording and collating all publicly available damage and casualty information, a preliminary global database of earthquake field data and its potential use for analyses have been outlined in this paper. It is hoped that the Cambridge University Earthquake Damage Database (CUEDD) will add significant value to earthquake estimation models in the future.

5.6 Access to CUEDD

The Cambridge University Earthquake Damage Database (CUEDD) can be accessed at www.ceqid.org. Please visit the website and send comments to Robin Spence robin.spence@carltd.com or Emily So emily.so@carltd.com.

Acknowledgments CUEDD has been developed by Cambridge Architectural Research Ltd. The project team has included Robin Spence, Antonios Pomonis, Emily So, Keiko Saito, Victoria Lee, Hermione Tuck, Aiko Furukawa, Janet Owers and Susanna Jenkins. CAR has worked in collaboration with the PAGER team at US Geological Survey, Golden Colorado, David Wald and Kishor Jaiswal. The database and website design were by Simon Ruffle and Vicky Smith of Stride Design. Financial support for the development of CUEDD has been provided by the Coburn Foundation. Several damage surveys have been sourced from the personal archive of Andrew Coburn; other contributions have come from Antonios Pomonis, the EU Centre, Pavia, and Jim Cousins of GNS, New Zealand.

Part II
Casualty Loss Modelling

Chapter 6
Earthquake Casualty Models Within the USGS Prompt Assessment of Global Earthquakes for Response (PAGER) System

K.S. Jaiswal, D.J. Wald, P.S. Earle, K.A. Porter, and M. Hearne

Abstract Since the launch of the USGS's Prompt Assessment of Global Earthquakes for Response (PAGER) system in fall of 2007, the time needed for the U.S. Geological Survey (USGS) to determine and comprehend the scope of any major earthquake disaster anywhere in the world has been dramatically reduced to less than 30 min. PAGER alerts consist of estimated shaking hazard from the ShakeMap system, estimates of population exposure at various shaking intensities, and a list of the most severely shaken cities in the epicentral area. These estimates help government, scientific, and relief agencies to guide their responses in the immediate aftermath of a significant earthquake. To account for wide variability and uncertainty associated with inventory, structural vulnerability and casualty data, PAGER employs three different global earthquake fatality/loss computation models. This article describes the development of the models and demonstrates the loss estimation capability for earthquakes that have occurred since 2007. The empirical model relies on country-specific earthquake loss data from past earthquakes and makes use of calibrated casualty rates for future prediction. The semi-empirical and analytical models are engineering-based and rely on complex datasets including building inventories, time-dependent population distributions within different occupancies, the vulnerability of regional building stocks, and casualty rates given structural collapse.

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6.1 Introduction

In the last decade, destructive earthquakes have struck throughout the globe and tragically claimed over 200,000 lives (e.g., Bam 2003, Morocco 2004, Kashmir 2005, Indonesia 2006, Peru 2007, Wenchuan 2008, and L'Aquila 2009). Due to the complexity associated with a large earthquake in terms of hazards (including its size, location and rupture uncertainties, and spatially variable shaking characteristics), as well as with the built environment (building and infrastructure vulnerability and population exposure characteristics at the time of earthquake), it often requires days, weeks or sometime months before the scope and extent of an earthquake disaster is understood. Time is of the essence in the post-earthquake arena and any delays in understanding the scale of the disaster often hampers the post-disaster responses and proves costly both socially and economically. Several aspects of an earthquake, including those of a seismological, engineering, and socio-economical nature must be understood and incorporated effectively before the impact of an earthquake can be predicted. In the realm of rapid earthquake casualty and loss modelling, this requires comprehensive assessment of earthquake hazard, seismic vulnerability of built environment and associated exposure, and finally a framework that computes losses in real-time. Tools developed at the National Earthquake Information Center, including the USGS ShakeMap and Did You Feel It? systems, provide rapid ground shaking intensity estimates immediately after an earthquake anywhere in the world (Wald et al. 2008a). The current Prompt Assessment of Global Earthquakes for Response (PAGER) system utilises the USGS's near real-time earthquake solutions, and estimates population exposure at various levels of shaking intensities. Several datasets have been compiled during the development of PAGER system, such as (i) PAGER-CAT, which tabulates earthquake magnitude, location, depth and fatality/loss information specific to individual earthquakes (Allen et al. 2009a), (ii) Atlas of global earthquake ShakeMaps (shaking hazard maps) for the past 35 years (Allen et al. 2009b), and (iii) EXPO-CAT, a catalogue of estimated population exposure at different shaking intensities created by hindcasting present day population to date of the event. These products have provided unique opportunities to study past earthquakes and perform comprehensive loss assessment using several different approaches. With the addition of the new loss computation engine within the PAGER system, we propose development of a exposure- and fatality-based alert system which provides an estimation of the likelihood of a range of fatalities caused by an earthquake. Tools developed for PAGER can also be used for effective pre-disaster planning for major damaging earthquakes anywhere in the world. Such a system is of paramount importance, especially to inform early and rapid post-earthquake decisions about humanitarian assistance, before ground truth and news information are acquired.

6.2 Inputs for Loss Estimation

6.2.1 Hazard

Based on a certain predefined magnitude threshold (M > 3.5 within US and M > 5.5 at global scale) registered by National Earthquake Information Center and the Advanced National Seismic System, the USGS Global ShakeMap system is triggered automatically and produces shaking hazard map in terms of ground motion parameters (Modified Mercalli shaking intensity, peak accelerations, peak velocities and spectral accelerations at 0.3 and 1.0 s period) at a resolution of approximately 1 km^2. The USGS ShakeMap system chooses the most appropriate ground motion prediction equation (GMPE) from a suite of GMPEs based on the seismogenic and tectonic conditions at the earthquake location. It uses conversion equations to transform ground motion estimates into other important shaking hazard parameters and also corrects the estimated ground motions for local site conditions (see Wald and Allen 2007, for more details). This site-corrected shaking hazard forms the basis for vulnerability and loss estimation for the PAGER system.

6.2.2 Vulnerability

The PAGER system consists of three vulnerability models, namely empirical, semi-empirical, and analytical which are discussed in the Sect. 6.3. The effective fatality rate within the empirical model is defined using a two-parameter lognormal cumulative distribution function, the coefficients of which are directly derived from past fatal earthquakes. The semi-empirical and analytical vulnerability models are forward predicting models in which the damage and loss analyses are based on site and structure-specific response analysis but applied at a regional scale. The semi-empirical model relies solely on fatalities caused due to building collapses and uses structure-specific collapse fragility functions defined in terms of Modified Mercalli shaking intensities (MMI), whereas the analytical model uses the HAZUS capacity-spectrum method to perform structural damage analysis.

6.2.3 Exposure

Several inputs are necessary in order to perform exposure analysis within the PAGER system. These are (i) LandScan 2007 gridded population database

(Bhaduri et al. 2002), (ii) the Global Rural-Urban Mapping Project (GRUMP) database (CIESIN 2004), (iii) demographic data compiled by the United Nations, data published by population census of different countries, CIA fact book on workforce data by sector of employment (https://www.cia.gov/library/publications/the-world-factbook), and (iv) the PAGER building inventory database, compiled using multiple sources and contributions from the WHE-PAGER project (Jaiswal and Wald 2008). Details of grid based exposure analysis necessary for PAGER semi-empirical and analytical models are discussed in the next section.

6.3 Loss Estimation Models

Researchers in the past have attempted to perform earthquake casualty/loss estimation at local or regional levels and advocated various approaches depending upon type of data, spatial applicability, and modelling principles. These different techniques can be classified into variants of three distinct approaches, namely empirical, analytical, and hybrid (or semi-empirical) approaches. Empirical approaches generally utilize earthquake data associated with past fatal earthquakes to derive regression parameters to be used for future prediction. Analytical (also called mechanistic) approaches employ end-to-end modelling calculations comprising of hazard, structural, damage, and loss analyses. Hybrid approaches are either simplified analytical approaches or approaches in which damage statistics of past earthquakes are directly utilized in the realm of structural damage analysis via modelling observed damage as a function of shaking intensities. The following section provides a detailed description of the three loss computation models that have been implemented within the PAGER system.

6.3.1 Empirical Model

Jaiswal et al. (2009a) developed a new global empirical model that utilises historical earthquake casualty data and provides a country or region-specific earthquake fatality rate as a function of shaking intensity. Unlike previous empirical approaches proposed by various researchers (Samardjieva and Badal 2002; Nichols and Beavers 2003) that advocates use of earthquake magnitude as a regression variable, Jaiswal et al.'s procedure utilises shaking intensity, a spatially varying parameter and an indicator of direct impact of ground motion on built environment. Earthquake magnitude only indicates the size of an earthquake and sometimes can be completely misleading for comparison with damage due to large variability in the shaking hazard for a given magnitude and population exposure.

6.3.1.1 Empirical Fatality Rate

Fatality rate (ν), which is function of shaking intensity (*S*), can be expressed in terms of a two-parameter lognormal distribution function as follows:

$$\nu(S) = \Phi\left[\frac{1}{\beta}\ln\left(\frac{S}{\theta}\right)\right] \tag{6.1}$$

where Φ is the standard normal cumulative distribution function. The fatality rate depends on the two free parameters of the cumulative distribution function of the lognormal distribution namely, θ and β. Let $P_\mathrm{i}(S_j)$ denote an estimated population exposed to shaking intensity S_j for an event *i*. Then the expected number of fatalities $E[L]$ can be denoted as

$$E_i[L] = \sum_j \nu_i\left(S_j\right)P_i\left(S_j\right) \tag{6.2}$$

In order to estimate the total number of fatalities from any given earthquake, we need to find (i) population exposure at each shaking intensity level, and (ii) the fatality rate associated with the shaking intensity. Suppose O_i is the number of recorded deaths for an earthquake *i*; we can determine the parameter of the distribution function (i.e., estimated fatality rate) in such a way that the residual error (i.e., error estimate between estimated and recorded deaths) is minimised. Jaiswal et al. propose a norm that provides a search space for minimizing the residual error associated with both low and high fatality earthquakes simultaneously. The objective function to determine the residual error is given as

$$\varepsilon = \ln\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(E_i - O_i\right)^2}\right) + \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[\ln\left(E_i / O_i\right)\right]^2} \tag{6.3}$$

We use a standard iterative search algorithm available in Matlab Ver., R2007a for minimizing the objective function in which E_i is defined in terms of Eq. (6.2) which contains fatality rate (ν) defined using θ and β as described in Eq. (6.1). It is assumed that the recorded number of deaths from an earthquake in the catalogue is free from any errors and is generally obtained from a well documented, peer reviewed source of literature or dataset for a particular earthquake. Figure 6.1a and b demonstrates the result of using Eq. (6.3) for Italian and Indian earthquakes between 1973 and 2007. Earthquakes with zero recorded deaths have been taken as 0.1 deaths for calculation purposes, and earthquakes without a recorded number of deaths (zero or otherwise) are ignored. Except for a few outliers, the model estimates the fatalities for most of the events within one order of magnitude, with approximately equal accuracy at low and high recorded deaths.

6.3.1.2 Uncertainty Estimation

The total uncertainty in hindcasting the median loss estimates for past fatal earthquakes is represented using the error term (ζ), where:

$$\zeta = \sqrt{\frac{1}{N-2}\sum_{i=1}^{N}\left[\ln\left(E_i + 0.5 / O_i + 0.5\right)\right]^2} \tag{6.4}$$

The expected value of actual/observed conditional loss in Eq. (6.4) can be obtained by performing linear regression. The error term is a combined measure of total variability associated with catalogue earthquakes (in which each earthquake has certain inherent errors associated with their epicentral location, ShakeMap's estimates of ground motion, accuracy of estimated population exposure, accuracy in terms of catalogue fatality count or other socio-economic factors) and each of them cannot be separated easily unless sufficient data are collected on each of these factors to isolate and model their independent contributions. It is expected that such error will always be part of the total error in predicting future fatalities for that region or country.

For PAGER alert purposes, we also need to provide the probability estimate associated with different alert levels such that the actual deaths may exceed certain predefined alert thresholds (see Jaiswal et al. 2009a). The probability *P* that the actual death *d* may be between predefined thresholds *a* and *b* is given as:

$$P\left(a < d \le b\right) = \Phi\left[\frac{\log(b) - \log(E)}{\xi}\right] - \Phi\left[\frac{\log(a) - \log(E)}{\xi}\right] \tag{6.5}$$

6.3.1.3 Regionalisation

In order to estimate the empirical fatality rate for countries with few or no fatality data, Jaiswal et al. (2009a) proposes aggregation of fatal events from like-countries at a regional level through a scheme that focuses on likely indicators of comparable country vulnerability. The regionalisation scheme combines the information specific to geography, building inventory (Jaiswal and Wald 2008), and socio-economic similarities defined using Human Development Index (HDI), and climatic classification scheme by Koppen Climate maps (Kottek et al. 2006). Socio-economic conditions and climate affect the way people live and also tend to influence building construction and maintenance practices. Figure 6.1c demonstrate the development of region-based fatality model for Iraq combining regional earthquakes that have occurred in neighboring countries such as Iran, Pakistan, and Afghanistan.

We illustrate the spatial variation of seismic-hazard independent mortality by estimating fatalities per 1,000 people when exposed at shaking intensity IX in Fig. 6.2. Clearly, future large earthquakes in countries like Iran, Pakistan and other south Asian countries will tend to produce the highest fatalities, whereas countries

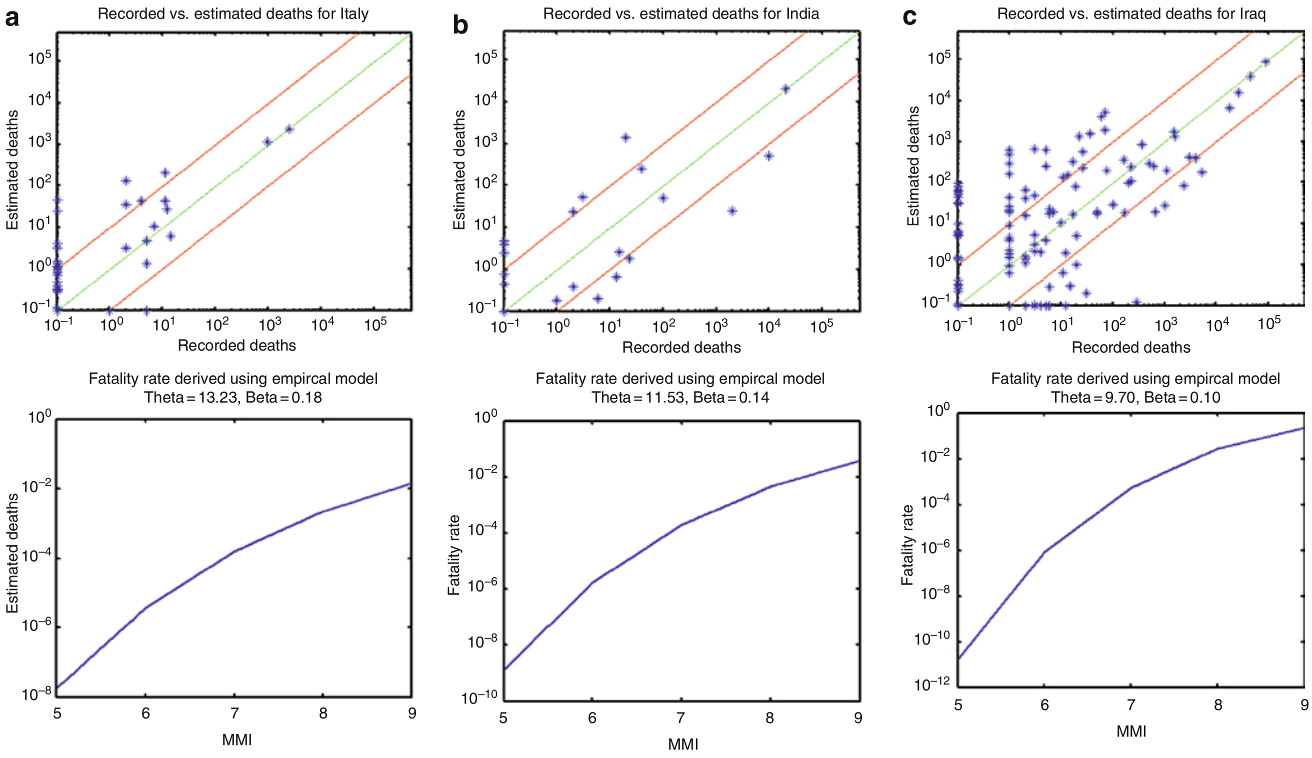

Fig. 6.1 Empirical fatality model derived using historical (1973–2007) fatal earthquakes. The model is country-specific for (**a**) Italy and (**b**) India. For the case of (**c**) Iraq, it is derived using regional fatal earthquake recorded in Iraq, Iran, Afghanistan and Pakistan

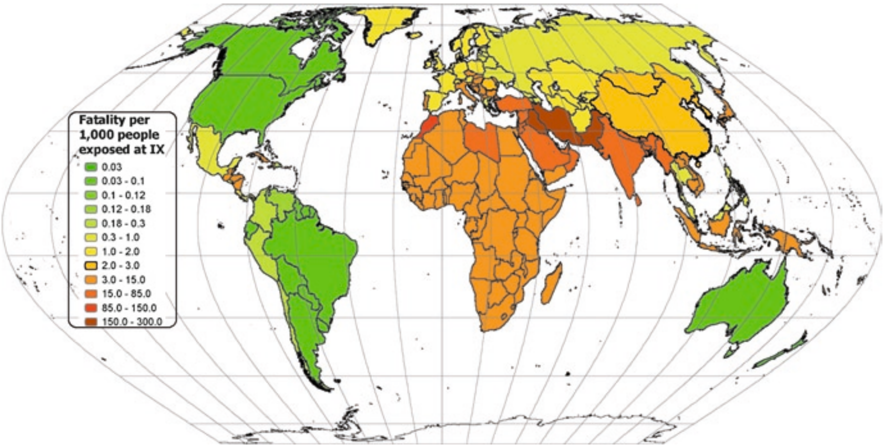

Fig. 6.2 PAGER empirical model showing earthquake fatalities estimated per 1,000 people exposed at MMI IX irrespective of shaking hazard

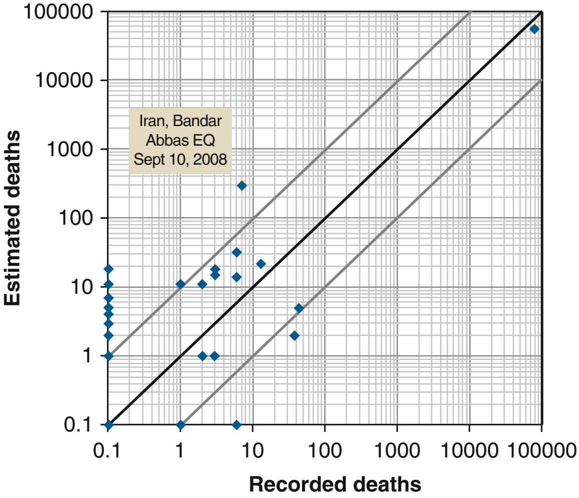

Fig. 6.3 Fatality prediction using empirical model for global earthquakes recorded in 2008. The model overestimated fatalities for the Bandar Abbas earthquake in Iran which killed seven and injured 47 people

like United States, Canada, and Australia remain less vulnerable irrespective of their seismic hazard. It is worth noting that due to the lack of sufficient large earthquakes in eastern South America, we tend to underestimate the seismic vulnerability. The PAGER empirical model (v1.0) has been implemented within the *lossPAGER* system since beginning of 2008. Figure 6.3 illustrates out of a total 139 earthquakes, 100 were non-fatal for which the empirical model predicted zero fatalities (therefore all are shown in lower left corner of Fig. 6.3 at 0.1 deaths).

6.3.2 Semi-Empirical Model

As forward estimation model, earthquake vulnerability within the semi-empirical model is defined in terms of probability of collapse of a particular structure type given the input shaking intensity. Let us assume that there are a total of n grid cells with m structure types. The shaking intensity (expressed in terms of MMI) associated with each grid cell i is denoted as S_i and j is an index representing each structure type for which FR_j is the fatality rate given collapse. Let P_i denote the total population at grid cell i, and f_{ij} denote the fraction of the population at location i in structure type j at the time of the earthquake. If the collapse fragility or mean collapse ratios associated with each structure type j at intensity S_i are expressed as $CR_j(S_i)$, then we can express the total estimated fatalities $E[L]$ over n grid cells as:

$$E[L] \approx \sum_{i=1}^{n} \sum_{j=1}^{m} P_i . f_{ij} . CR_j \left(S_i\right) . FR_j \tag{6.6}$$

6.3.2.1 Collapse Ratios (CR) or Collapse Fragility Functions

In order to estimate the collapse fragility, PAGER collaborated with WHE experts from 26 countries to gather country-specific vulnerability data for the most common building types (Porter et al. 2008). After performing rigorous analysis of building-specific fragility functions on country-specific data and hindcasting losses for past fatal earthquakes, we developed a suite of PAGER structure-type (PAGER-STR) specific collapse-fragility functions (Jaiswal et al. 2011) that can be used within the PAGER semi-empirical model. The collapse fragility defined in terms of shaking intensity S is given as:

$$CR_j(S) = A_j \times 10^{\left(\frac{B_j}{S - C_j}\right)} \tag{6.7}$$

The parameters A_j, B_j, C_j can be determined for each structure type j either from structure specific collapse statistics obtained from past earthquakes or retrieving best fit parameters to the expert judgment data gathered through the WHE-PAGER project. Table 6.1 summarizes the parameters obtained for some PAGER structure types from WHE-PAGER survey data.

6.3.2.2 Fatality Rates (FR) Given Structural Collapse

Building collapses are the main contributor to total fatalities worldwide (Spence 2007) and the PAGER fatality estimates are mainly deduced from modelling the collapse fragilities of different structure types within the current framework. Although the fatality rates tend to vary from one earthquake to another, even given

Table 6.1 Collapse fragility parameters for selected building types (Jaiswal et al. 2011)

Building Type	A	B	C	Fatality Rate
Adobe buildings	10.76	−5.34	4.05	0.06
Mud wall buildings	2.56	−1.69	5.18	0.06
Nonductile concrete moment frame	3.42	−5.03	5.62	0.15
Precast framed buildings	0.85	−2.35	5.90	0.10
Block or dressed stone masonry	9.52	−4.89	5.32	0.08
Rubble or field stone masonry	6.17	−4.58	5.03	0.06
Brick masonry with lime/cement mortar	8.03	−7.59	4.60	0.06
Steel moment frame with concrete infill wall	0.44	−6.10	4.40	0.14

similar levels of ground motions or building vulnerabilities, these rates still are derived by performing statistical analysis on casualty data of several earthquakes. For most United States (US) construction types, the fatality rates given collapse are directly taken from the HAZUS (NIBS-FEMA 2006) casualty rates associated with injury severity level 4 at the complete damage state. However for non-US construction types, we used generic casualty rates recommended by UCAM for injury category-5 (deaths) associated with damage grade D5 (partially or totally collapsed) under the auspices of LessLoss project as shown in Table 6.1.

6.3.3 Analytical Model

The analytical model implemented in the current USGS PAGER system is based on HAZUS capacity-spectrum methodology that estimates the response of a structure from spectrum demand and spectral-capacity curves (NIBS-FEMA 2006). The demand spectrum represents the site adjusted input ground motion typically derived from elastic acceleration response spectra, whereas the spectral capacity of a structure is expressed in terms of idealized curvilinear curve defined by yield and ultimate control points. The capacity-spectrum method provides the estimate of median response of an idealized nonlinear single degree of freedom (SDOF) oscillator where the spectral-capacity and demand curves intersect. This point is referred to as the performance point and it is obtained by adjusting the response to account for site soil amplification and hysteretic energy dissipation through an iterative procedure. The spectral displacement S_d associated with the performance point forms an input to fragility functions that gives the probability of different damage states. The damage and casualties associated with slight, moderate and extensive damage states are ignored for PAGER purposes since they form a very small fraction of total fatalities. Porter (2009) simplifies the iterative process for PAGER purposes and directly tabulates the mean-collapse fragilities and indoor fatality rates as a function of 5% damped spectral accelerations at 0.3 and 1.0 s periods. The fatality rates given structural collapse (*FR*) are same as in case of the semi-empirical approach.

6.3.4 Grid-Based Loss Computation

Both semi-empirical and analytical models employ grid-based fatality computation (Fig. 6.4) in which we determine the density class of a particular cell *i* using the GRUMP dataset, then determine the fraction of indoor population in residential and non-residential (work places, e.g., commercial, service, industry, schools, administrative buildings, etc.) occupancies based on local time of day and a demographic dataset. We assume three time domains, namely: Day time (10 am–5 pm), Night time (10 pm–5 am), and Transit time (5 am–10 am and 5 pm–10 pm), used for the purpose of determining the fraction of the total population in residential and non-residential buildings. The total outdoor population determined at the time of the earthquake is ignored at this stage due to the lack of availability of vulnerability functions and casualty rates specific to lifeline systems or with outdoor populations.

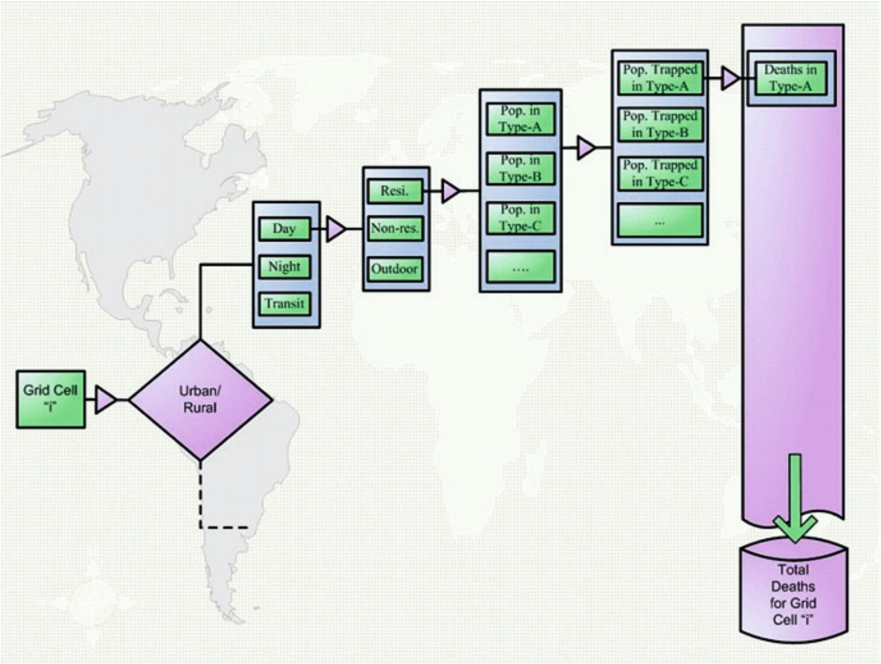

Fig. 6.4 Grid-based fatality computation for PAGER engineering loss estimation models

Once the total indoor population in both residential and non-residential is determined, we classify them into different PAGER structure types using country-specific inventory defined in terms of density (urban/rural) and occupancy (residential/non-residential) types. The total indoor population by PAGER structure type is determined as a function of time of day, population density characteristics, and occupancy type, and forms an input for damage and loss estimation as described in the previous section. We estimate the total fatalities from each PAGER structure type using either the semi- empirical model (in which the intensity associated with grid cell *i* is used) or using the analytical approach (in which the spectral acceleration at 0.3 and 1.0 s time periods is used). We then sum the total fatalities over all the structure types of grid cell *i* and later over all grid cells associated with a particular earthquake.

6.4 Conclusions

Rapid earthquake loss estimation tools such as PAGER that provide the estimation of likelihood of building and infrastructure damage, deaths, and financial losses after an earthquake help responders understand the scale of disaster and determine the demand in terms of humanitarian needs in the aftermath of a disaster. The PAGER empirical model accommodates the total variability through a country-specific error term obtained by hindcasting deaths in past earthquakes. While the availability of data on large and fatal earthquakes in the past serves as a backbone for the empirical model, these datasets also provide a useful benchmark for calibrating losses using both hybrid and analytical approaches. The analytical model uses fragility functions that relate the probability of various damage states or collapse given the response of the building type to certain input ground shaking. In the case of the analytical approach, the vulnerability parameters associated US building types are adopted from the HAZUS model; however it is extremely difficult to gather the complex structural parameters needed to define the vulnerability and performance for non-US construction types. The WHE-PAGER project (through a network of international experts) is working towards developing protocols for collection of critical parameters using a unified approach and developing strategy to encourage researchers worldwide to contribute data through an open-source environment to improve the vulnerability modelling capabilities.

Chapter 7
Loss Estimation Module in the Second Generation Software QLARM

G. Trendafiloski, M. Wyss, and P. Rosset

Abstract Currently, we are constructing our second-generation loss estimation tool QLARM (earthQuake Loss Assessment for Response and Mitigation) and upgrading the input database to be used in real-time and scenario mode. Our tool and database are open to all scientific users. The estimates include: (1) total number of fatalities and injured, (2) casualties by settlement, (3) percent of buildings in five damage grades, and (4) a map showing mean damage by settlement. The QLARM worldwide database of the elements-at-risk consists of city models constructed with the following parameters: (1) soil amplification factors, (2) distribution of building stock and population into vulnerability classes of the European Macroseismic Scale (EMS-98). We calculate damage and losses using vulnerability curves, regionally-based collapse models, and casualty matrices pertinent to EMS-98 vulnerability classes as a function of the seismic intensity. We calibrate our tool for different countries and regions worldwide considering macroseismic, damage, and loss data from past events. Thus, we calculate human losses for past earthquakes correctly to within a factor of 2, on average. Recently, we used QLARM to estimate expected human losses for the metropolitan area of Lima in case of a hypothetical earthquake of magnitude 8 in the immediate vicinity offshore of Lima.

7.1 Introduction

We have seven years of experience in distributing loss estimates by email in near-real-time for any earthquake with $M \geq 6$ worldwide. This service is free and open to anyone. Our loss estimates reach the consumers in 30 min (median) after the earthquake in question (Wyss and Zibzibadze 2009). In 95% of the cases, we have been able to differentiate disastrous from inconsequential earthquakes, but we have also

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issued a few incorrect estimates for various reasons. Our struggle to reduce the influence of error sources will go on for years to come.

Currently, we are constructing our second-generation loss estimation tool QLARM (http://qlarm.ethz.ch) in collaboration with the Swiss Seismological Service (SED-ETH, Zurich) and we are upgrading our database of elements-at-risk to be used in real-time or scenario mode. Our steps in estimating earthquake-related human losses are the following. (1) We need to know the epicentre (position) of the earthquake, its depth, and magnitude. (2) From these parameters, we calculate the ground shaking for settlements in our database as a function of distance from the epicentre, using global and regional attenuation laws. (3) If possible, we would like to know the soil conditions in each settlement, because some soils amplify the strong ground motion. (4) To calculate what damage the ground motion causes, we need to know the distribution of buildings into classes of resistance to ground shaking. (5) For estimating the effect of collapsed and damaged buildings on people, we need to know the distribution of people into the building classes and the casualty matrix. (6) We also need to know the population for each settlement, in order to convert the percentages from the casualty matrix into numbers of people killed and injured in each settlement. (7) Finally, it is also desirable to have accurate information about when people are in what buildings, as a function of the time of day, and as a function of the seasons. In developing countries, the focus of our efforts, it is rare that all pieces of information listed above are available and complete. Therefore, we built a strategy to construct the database and loss estimation tool based on partial information.

The results of our calculations include the following: (1) the expected percentage of buildings in each of five damage states in each settlement, (2) the mean damage state in each settlement, (3) the numbers of fatalities and injured, with error estimates, in each settlement.

Recently we used QLARM to estimate human losses in Lima. Peru had enough historic earthquakes for which intensities, fatalities and injuries were reported, such that we were able to calibrate our computer tool. Therefore, we feel confident that our loss estimates for future earthquakes are reasonably reliable, within the large margins of uncertainties that are associated with a scenario exercise like this.

7.2 QLARM Database

Focusing on developing countries, we construct (Trendafiloski et al. 2009b): (1) *point city models* for the cases where only summary data for the entire city are available; and, (2) *discrete city models* where data regarding city sub-divisions (districts) are available. The city models are available for all settlements (urban and rural) regardless of size. The parameters we introduce in the QLARM database are the following: (1) soil amplification factors; (2) distributions of building stock and population into vulnerability classes; and (3) the most recent population numbers by settlement or district.

We use two approaches to estimate soil amplification: (1) *local approach* based on the existing data regarding soil properties, microzonation, and geological maps to derive the amplification factor for each discrete city model; (2) *global approach* based on Vs30 values derived from topographic slopes (Allen and Wald 2007). An average Vs30 value is then calculated from the values on the grid of data (Global Vs30 Map Server of the USGS) at a certain radius of each settlement and converted into an amplification factor. We assign the vulnerability classes to different building types considering the vulnerability table given by the European Macroseismic Scale EMS-98 (Grünthal 1998). We construct the building and population distributions using the percentage of the number of buildings and population belonging to a particular vulnerability class as shown in Eq. 7.1.

$$DB(VC) = \frac{NB(\in VC)}{NB} \quad DP(VC) = \frac{NP(\in VC)}{NP} \tag{7.1}$$

where DB(VC) is the distribution of buildings in a particular vulnerability class (VC) [in%]; DP(VC) is the distribution of population in a particular vulnerability class [in%]; NB $(\in VC)$ is the number of buildings belonging to particular vulnerability class; NP $(\in VC)$ is the number of people occupying a particular vulnerability class; NB is the total number of buildings; NP is the total population.

We construct the QLARM population database using national census data and the online sources World Gazetteer and Geonames. In addition, we updated the database contained in QUAKELOSS (Shakhramanjyan et al. 2000; Shakhramanjyan et al. 2001) to estimate current values for small settlements. Regarding building exposure, we used various sources of information hereafter ordered by the quality of the data provided: (1) national census data, (2) opinion of local experts, (3) World Housing Encyclopedia and PAGER database, (4) existing QUAKELOSS database.

Once the parameters of the elements-at-risk and soil amplification are estimated, we geo-reference them to the centroid of the adopted city model (point or discrete). The distributions of buildings and population we use are different in three city size classes: (1) large cities (more than 20,000 inhabitants); (2) medium cities (2,000–20,000 inhabitants); and, (3) small (rural) settlements (less than 2,000 inhabitants). The city size classes are country or region-specific. We use the population numbers in parentheses as given by the UN Statistics Division as defaults. In addition to the spatial characteristics, the population distribution varies as a function of time. Thus, in our models we incorporate simplified daily population dynamics as suggested by Coburn and Spence (Coburn and Spence 2002).

7.3 QLARM Loss Estimation Module

The characteristics of the QLARM loss estimation module are the following: (1) Calculation of the human losses due to expected damage caused by ground shaking. We do not consider other types of seismic hazard such as tsunamis, landslides or earthquake-related fires; (2) The seismic demand is expressed in terms of (a) macroseismic (seismic intensity) or (b) instrumental (PGA/PGV) parameters. (3) We adopt the damage grade scale as given by EMS-98 (D_0 – no damage; D_1 – slight damage; D_2 – moderate damage; D_3 – heavy damage; D_4 – very heavy damage;

D_5 – destruction). (4) The injury severity scale is as given by HAZUS (NIBS and FEMA 2003) (C_1 – non-injured; C_2 – slightly injured; C_3 – moderately injured; C_4 – seriously injured; C_5 – dying or dead).

7.3.1 Damage Estimation

The building damage in QLARM is calculated using the European Macroseismic Method (Giovinazzi 2005). The vulnerability models are pertinent to EMS-98 vulnerability classes A to E and correlate the mean damage grade μ_D ($0 \le \mu_D \le 5$) with the seismic intensity (I) and the vulnerability index (V_I), Eq. 7.2.

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 6.25V_I - 13.1}{2.3}\right)\right] \tag{7.2}$$

The parameter V_I defines the membership of the particular building type in a specific vulnerability class. The membership is not deterministic and defines the most probable class and its plausible and ultimate bounds. The probabilities of occurrence of damage grade D_i for seismic intensity I_J (percentage of buildings of damage grade D_i) are then beta-distributed (Giovinazzi 2005) considering the ranges of the mean damage grade. Thus, we create a damage probability matrix for a particular vulnerability class.

The values of the vulnerability indices for the EMS-98 vulnerability classes (Giovinazzi 2005) are defined in the following ranges (Table 7.1): (1) $\mathbf{V_o}$ is the most probable value of the vulnerability index V_I for a specific building type (considered as a centroid of the membership function). (2) [$\mathbf{V^-}$; $\mathbf{V^+}$] are the bounds of the plausible range of the vulnerability index V_I for a specific building type (obtained as the 0.5-cut of the membership function). (3) [$\mathbf{V_{min}}$; $\mathbf{V_{max}}$] are the upper and lower bounds of the possible values of the vulnerability index V_I for a specific building type.

7.3.2 Estimation of Human Losses

We estimate the human losses using the casualty event-tree model proposed by Stojanovski and Dong (1994). The probability of occurrence of casualty state C_k (k = 1,5) for seismic load I_J is therefore calculated as a product of the damage probabilities for seismic load I_J and the casualty probabilities for damage grade D_i, Eq. 7.3,

Table 7.1 Values of the vulnerability indices for EMS-98 vulnerability classes

Vuln. class	V_{min}	V^-	V_o	V^+	V_{max}
A	0.78	0.86	0.9	0.94	1.02
B	0.62	0.7	0.74	0.78	0.86
C	0.46	0.54	0.58	0.62	0.7
D	0.3	0.38	0.42	0.46	0.54
E	0.14	0.22	0.26	0.3	0.38

$$
\begin{aligned}
P(C_1I_J) &= \sum_{i=1}^{3} P(D_iI_J)\,\mathrm{P}(D_i\mathrm{C}_1) + P(D_{NC}I_J)\,P(D_{NC}C_1) + P(D_CI_J)\,P(D_CC_1)\,|_{J=1,n} \\
P(C_2I_J) &= \sum_{i=1}^{3} P(D_iI_J)\,\mathrm{P}(D_i\mathrm{C}_2) + P(D_{NC}I_J)\,P(D_{NC}C_2) + P(D_CI_J)\,P(D_CC_2)\,|_{J=1,n} \\
P(C_3I_J) &= \sum_{i=1}^{3} P(D_iI_J)\,\mathrm{P}(D_i\mathrm{C}_3) + P(D_{NC}I_J)\,P(D_{NC}C_3) + P(D_CI_J)\,P(D_CC_3)\,|_{J=1,n} \\
P(C_4I_J) &= \sum_{i=1}^{3} P(D_iI_J)\,\mathrm{P}(D_i\mathrm{C}_4) + P(D_{NC}I_J)\,P(D_{NC}C_4) + P(D_CI_J)\,P(D_CC_4)\,|_{J=1,n} \\
P(C_5I_J) &= \sum_{i=1}^{3} P(D_iI_J)\,\mathrm{P}(D_i\mathrm{C}_5) + P(D_{NC}I_J)\,P(D_{NC}C_5) + P(D_CI_J)\,P(D_CC_5)\,|_{J=1,n} \\
P(D_CI_J) &= k_C(I_J)\big[P(D_4I_J) + P(D_5I_J)\big] \quad P(D_{NC}I_J) = \big(1 - k_C(I_J)\big)\big[P(D_4I_J) + P(D_5I_J)\big]
\end{aligned}
\tag{7.3}
$$

where $\mathrm{P}(\mathrm{D}_i\mathrm{I}_J)$ is the probability of occurrence of damage grades i = 1 to 3 for seismic intensity I_J; $\mathrm{P}(\mathrm{D}_{NC}\mathrm{I}_J)$ is the probability of having no collapse among the buildings with damage grades 4 and 5; $\mathrm{P}(\mathrm{D}_C\mathrm{I}_J)$ is the probability of having collapse among the buildings with damage grades 4 and 5; $\mathrm{k}_C(\mathrm{I}_J)$ is the collapse model; $\mathrm{P}(\mathrm{D}_i\mathrm{C}_k)$ is the probability of having casualty state C_k due to damage grade D_i.

The collapse model $\mathrm{k}_C(\mathrm{I}_J)$ determines the percent of collapsed buildings as a function of seismic intensity I_J out of the ones with damage grades 4 and 5. As a first approximation, we define discrete collapse models for vulnerability classes A to E for nine regions worldwide (Fig. 7.1) using the collapse rates for 26 countries worldwide, provided by the World Housing Encyclopedia (www.world-housing.net). The casualty probabilities compose the casualty matrices pertinent to vulnerability classes A

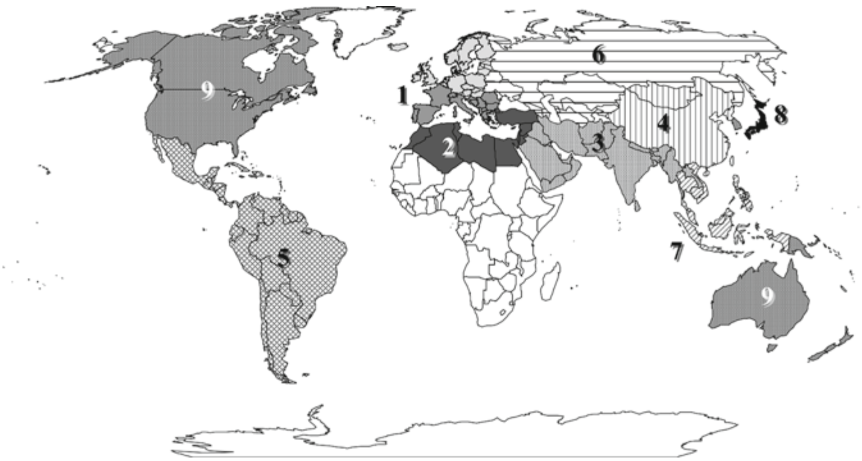

Fig. 7.1 Worldwide regions with different collapse models.1 – Europe (1a Northern and Central Europe; 1b Southern Europe); 2 – South-Eastern Mediterranean and Northern Africa; 3 – Middle-East, Southern and South-Eastern Asia; 4 – China region; 5 – Central and Southern America; 6 – Russia and Former Soviet Countries in Central Asia; 7 – South-Eastern Asia; 8 – Japan; 9 – Northern America, Australia, New Zealand

Table 7.2 Casualty matrix pertinent to vulnerability classes A and B based on HAZUS casualty rates for unreinforced masonry building type

	Damage grade					
Casualty state	D_0	D_1	D_2	D_3	D_4+D_5 (no collapse)	D_4+D_5 (collapse)
C_1	1	0.9995	0.99248	0.97796	0.8796	0.25
C_2	0	0.0005	0.0035	0.02	0.1	0.4
C_3	0	0	0.004	0.002	0.02	0.2
C_4	0	0	0.00001	0.00002	0.0002	0.05
C_5	0	0	0.00001	0.00002	0.0002	0.1

to E. As default values we use the HAZUS (NIBS and FEMA 2003) indoor casualty rates for building types corresponding to EMS-98 vulnerability classes (Table 7.2), which we are modifying based on observed fatality and injured rates (Wyss and Trendafiloski 2009).

7.4 Calibration and Validation of the Loss Estimating Tool

We calibrate the loss estimation model in four steps. (1) *Calibration of the attenuation law.* Calculation of the ground motion is the first step. So far, we have incorporated in QLARM the following relationships: (a) Intensity prediction - Shebalin (1968), Ambraseys (1985) and Fäh et al. (2003). (b) Ground motion prediction (PGA/PGV) - Huo and Hu (1992), Ambraseys et al. (1996), Boore et al. (1997), Youngs et al. (1997). The results of the calibration are parameters of the attenuation law that give the best fit to the macroseismic observations from past events. (2) *Calibration of the city models.* In this step we use the technique of redistribution of buildings and population into vulnerability classes (Trendafiloski et al. 2009b). We reassign the vulnerability classes to particular building types considering: the damage data from past events, vulnerability modifiers (Giovinazzi 2005) in case of data with higher resolution including structural details and expert judgment. (3) *Calibration of the collapse models.* We use observed collapse rates from past earthquakes to adjust the global collapse models for particular countries and to account for local building properties. (4) *Calibration of the casualty matrices.* The ratio (R) fatalities/injured depends on the resistance of the built environment and on the intensity of shaking. In the industrialised world, the median R for earthquakes since 1970 is 50. In the developing world, the median R is 2.5 (Wyss and Trendafiloski 2009). Thus we propose to use this ratio to adjust the casualty matrices pertinent to developing countries in Southern Asia where very low values of the ratio R are observed ($R < 1$) for seismic intensities larger than IX.

We perform the calibration step by step in the order given above. After every step, we validate the estimates against the observed human losses. Considering the uncertainty of the input parameters in the domain of our interest, developing countries, we calibrate our tool to calculate human losses for past earthquakes correctly to within a factor of 2, approximately, unless the number of fatalities are small, in which case our estimates usually come to within 100 of the reported number.

For example, we verified our tool for India before estimating possible future losses in the Himalayas, using 16 earthquakes (Wyss 2005). The prediction of losses in a possible earthquake in Kashmir, published before the October 2005 Kashmir event, was correct to within a factor of 2.4 (Wyss 2006). Examples of loss estimates better than a factor of 2 in real-time include the M8 Wenchuan 2008 (Wyss et al. 2009a), and the M6.3 L'Aquila, 2009 earthquakes (both published in real-time at www.wapmerr.org). For several countries we have calibrated QLARM, using Utsu's (2002) catalogue, completed for recent years from the list of significant earthquakes posted by the US Geological Survey on http://neic.usgs.gov/neis/epic/. For example, for Peru (Wyss et al. 2009b) there were 6 and for Iran 37 good quality events available for calibration that resulted in agreement of estimates with observation to factors near two.

7.5 Loss Scenarios for Lima

Recently, we calculated expected human losses in Lima in case of a hypothetical catastrophic earthquake in the immediate vicinity offshore of Lima. The basic earthquake source parameters were magnitude 8, at 33 km depth, and 15 km offshore of the beach of Lima (Wyss et al. 2009b).

7.5.1 Lima City Model

We modelled the city of Lima as consisting of 43 districts in which the population is known. For each district, we calculated an average amplification factor for the strong ground motion, based on a microzonation map with known soil types. The information regarding building properties for the 43 districts of Lima was extracted from the 2005 Census of Peru. It contained: (1) number of buildings per occupancy type; and (2) number of buildings per building type based on the type of exterior walls. This information is not perfect from the engineering point of view, but it helped to account for the differences of building properties in Lima districts and to refine the city model. We concluded that the population in vulnerability class A is fairly evenly distributed in the districts; it generally deviates from the average by one to two percent only. For vulnerability class C, the variation is larger (10%) and reaches over 20% for three districts.

7.5.2 Calibration of QLARM for Peru

For the case of Peru, we used Shebalin's (1968) attenuation law (Eq. 7.4) to calculate the decrease of the seismic intensity away from the source.

$$I = AM - B\log\sqrt{(r^2 + h^2)} + C \tag{7.4}$$

where M is magnitude; r is the epicentral distance; h is the hypocentral depth; A, B and C are parameters of the attenuation law.

We gathered intensity values reported for past earthquakes in the country and calculate attenuation parameters that give the best fit to the macroseismic data. Figure 7.2 shows an example of a match between calculated and observed intensities.

In a second step, we calibrated the Lima city model considering the performance of buildings during the 2007 Pisco earthquake and the collapse models pertinent to Central and South America as given by the World Housing Encyclopedia (Fig. 7.3).

The calibrated tool was validated against six recent Peruvian earthquakes since 1990 (Wyss et al. 2009b). Based on the comparison (Table 7.3) of observed with calculated casualties (fatalities plus injured), we conclude that QLARM estimates losses correctly within the criteria given in Section 7.4, if the parameters of the earthquakes are well known.

7.5.3 Expected Damage and Human Losses in Lima

For the adopted hypothetical M8 earthquake we expect that 30% of the residential building stock in Lima might be very heavily damaged or collapsed (Wyss et al. 2009b).

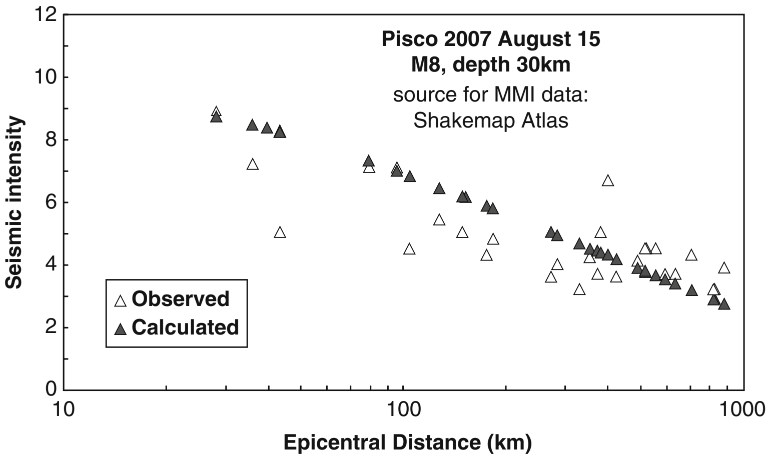

Fig. 7.2 Comparison of observed and calculated intensities (A = 1.5, B = 4.5 and C = 4.0) as a function of distance from the epicentre for the M8 earthquake of 2007 that occurred in the Lima/Pisco region. The observed intensities are in MMI scale

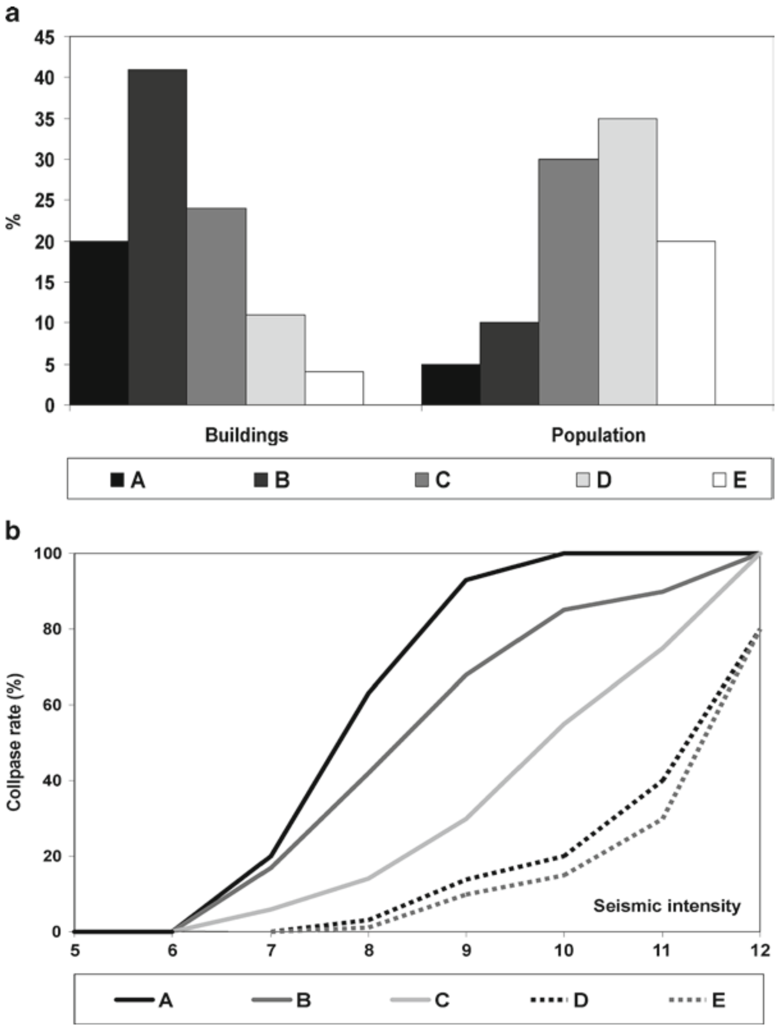

Fig. 7.3 Calibrated city model of Lima, (**a**) calibrated distributions of buildings and population, (**b**) collapse models for Central and South America

The range of average total fatalities in our scenarios is about 6,000–25,000 expected in Lima. For all of these estimates, an uncertainty of about 40% has to be applied, so the range is even larger. For the worst case (occupancy rate 80% at night instead of the 50% assumed) the numbers of total fatalities would be about 9,000 to 40,000 in Lima.

The range of injured for an occupancy rate of 50% is estimated at 66,000–230,000. The total number of injured in the worst case (occupancy rate 80%) is therefore esti-

Table 7.3 Peruvian earthquakes used as QLARM calibration events. Observed casualties are compared to mean estimates which have error of approximately ±40%.

							Fatalities		Injured	
Year	mm	dd	Long	Lat	Depth (km)	Mag	Obs	Calc	Obs	Calc
1990	5	30	−77.23	−6.02	24	6.5 (6.6)	135	80	800	610
1991	4	5	−77.09	−5.98	20	6.8	53	50	252	550
1996	2	21	−79.57	−9.62	33	6.6 (7.5)	12	0	56	50
1996	11	12	−75.68	−14.99	33	7.3 (7.8)	15	45	700	300
2001	6	23	−73.64	−16.26	33	8.2	139	360	2687	2100
2007	8	15	−76.51	−13.32	41	7.5 (8.0)	360*	310	1090	3070

* Excluding fatalities in the San Clemente church and the Embassy hotel

mated as 128,000–432,000. Given that this is an average number that has a 40% error margin, the number of injured could conceivably exceed half a million.

7.6 Discussion

Although we have successfully estimated losses due to earthquakes worldwide for the last 7 years, significant improvements in our accuracy will be achieved by the use of our second-generation loss estimation tool QLARM. The new calculation module, the methods, and the databases focus on the area of our interest, developing countries, in which only approximate information on building stock and population exists. Averaging is an important element in achieving approximately correct loss estimates with QLARM. With the limited information available, we cannot calculate damage or losses to a single, specific building. However, the errors in soil conditions and vulnerability of single buildings will average out, if we estimate the sum of the losses in a large number of buildings. Thus, our approach and strategy to model cities with incomplete information is applicable when creating city models for developing countries. It is this part of the world that needs most assistance with estimating losses due to earthquakes in real time, as well as in scenario mode.

The QLARM database and the damage estimation method use vulnerability classes rather than specific building types. Our observation is that distributions in terms of vulnerability classes can be used as input for estimating future losses, although the resolution of the data decreases when they are inferred from building types (Trendafiloski et al. 2009b). Carefully calibrated, our loss estimation tool QLARM calculates human losses for past earthquakes correctly to within a factor of 2, on average. Thus, we expect that it will reasonably estimate the losses that may be sustained in future earthquakes.

QLARM was recently used to calculate casualty potential due to future earthquakes in the vicinity of Lima. The tool was calibrated using six earthquakes in Peru since 1990 for which we have observations regarding damage and losses. We propose to calibrate our city models using earthquakes in a time-window of the past 10–15 years. We concluded that an earthquake of magnitude 8 in the vicinity of Lima would probably cause more than 10,000 fatalities. If a great earthquake ruptures the plate boundary outward of Lima, but its points of greatest energy release are not close to Lima, then the disaster could be an order of magnitude smaller. The number of injured would, however, not be reduced dramatically, if the major energy release were farther away. One would still have to expect more than 100,000 injured people and with the energy release close to Lima, 200,000 injured may need medical attention. Although these numbers of casualties are frightening, the percentage of the population killed and injured is moderate. For the M8+ scenarios, the percentages killed and injured are 0.2–0.3% and 2–3%, depending on the distance of the main energy release. This percentage is less severe than in earthquakes in Pakistan (M7.6, 2005) and Iran (Bam M6.6, 2003), but much worse than in earthquakes in the industrialised world.

To improve our services we propose to upgrade QLARM by including estimates regarding functionality of medical facilities in the affected region. Therefore we had already initiated methods of calculating post-disaster functionality and capacity of medical facilities based on their structural and functional vulnerability. This requires construction of a database of medical facilities worldwide, which we have begun to compile.

QLARM is still in a developing phase. However, taking part in the current initiative Global Earthquake Model, we will have an opportunity to compare QLARM estimates with the estimates of other similar tools.

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Chapter 8
Earthquake Casualties Estimation in Emergency Mode

N. Frolova, V. Larionov, and J. Bonnin

Abstract Rough estimations, in emergency mode, of expected casualties caused by strong earthquakes are very critical for taking the proper decisions about search and rescue operations, as well as rendering humanitarian assistance. Loss computations are started as soon as input data (earthquake source parameters) are available. The efforts are made to issue a likely assessment as quickly as possible (within 30–60 min in most cases). Improvement of the procedure is sought to shorten this delay. The chapter provides a description of simulation models used for fatality and injury assessment, based on buildings and structures which have suffered different damage states during strong earthquakes. The databases on buildings and population distribution, with global coverage, used for expected casualty estimation in emergency mode are analysed.

As information on the built environment is not homogeneous for all earthquake-prone countries, in order to avoid overestimation of losses with simulation model applications, it is proposed to use empirical relationships between number of casualties and earthquake magnitudes, obtained on the basis of more than 1,000 events characterised by anomalously high macroseismic effects.

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8.1 Description of Extremum System Simulation Models

This section describes the models for seismic hazard, vulnerability, damage and casualty estimates. All simulation models bring their own uncertainties and propagate the uncertainties of the previous steps of the estimation procedure. Actually, the problems of accuracy are considerably more complex than suggested in the previous sentence; in addition, to the classic behaviour of uncertain input data through each step of the procedure, the simulation models introduce biases whose influence on the final results is not easy to assess; this cannot be thoroughly discussed here.

8.1.1 Estimation of Shaking Field

Data about event source parameters are input for computation of the probable shaking field, in terms of "intensity". The authors follow the traditional way of expressing ground shaking; progress is badly needed to improve the situation and consider the true acceleration responsible for the damage observed.

The formula used is taken from Shebalin (1968).

$$I = bM - \nu \lg \sqrt{\Delta^2 + h^2} + c, \tag{8.1}$$

where Δ epicentral distance (km); h – source depth (km); M – magnitude. Coefficients in the formula are estimated by taking into account empirical data. In the research for the Balkan Catalogue the sets of these coefficients were proposed by Sbebalin and Karnik (Shebalin et al. 1974) for a detailed division of the territory under study. The estimations made by Shebalin for the former USSR were more general (Kondorskaya and Shebalin 1977). Long experience of the equation application (Shebalin 2003) showed that the region under consideration should be divided into a minimum number of sub-regions. Attenuation law parameters proposed for Europe are obtained from the report (Shebalin et al. 1998); these are listed in Table 8.1.

For other territories, these coefficients may be taken from literature or derived from statistical analysis of available data sets; one could alternatively use the average values: b= 1.5; v =3.5; c= 3 proposed by Shebalin (1968).

For loss computations in emergency mode, different attenuation law parameters are usually used. The example for the 2008 Kurchaloj earthquake shows that more

Table 8.1 Macroseismic field coefficients for Central and Southern Europe by Shebalin et al. (1998)

Region	b	v	c
Southern part $\varphi \leq 47$ N	1.5	4.0	3.8
Northern part $\varphi > 47$ N	1.5	3.5	3.6

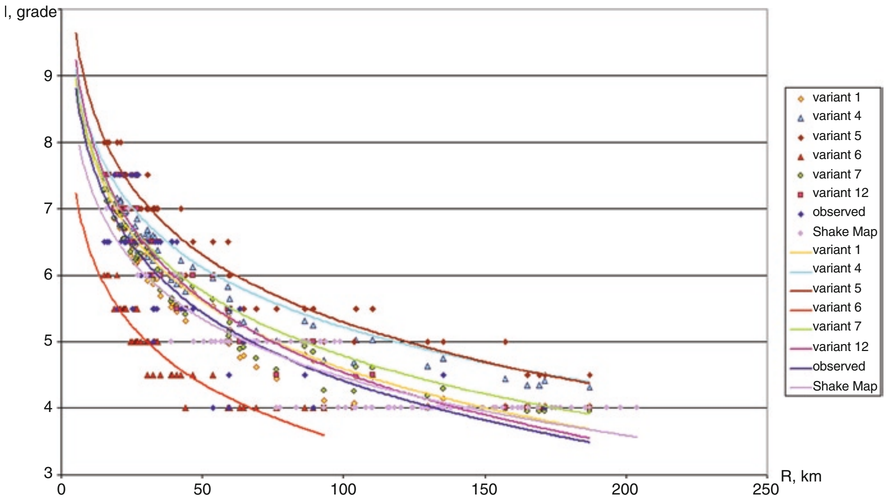


Fig. 8.1 Comparison of simulated shaking intensities with application of different attenuation law parameters and observed values

general parameters (variant 12) allow the simulation of shaking intensity which is close to observed values (Fig. 8.1). In computations different values of regional coefficients were used: variant 1 – proposed by Shebalin (Kondorskaya and Shebalin 1977) for Dagestan; variant 4 – proposed by Shebalin (Kondorskaya and Shebalin 1977) for the Northern Caucasus; variant 5 – proposed by Shebalin (Kondorkaya and Shebalin 1977) for the Caucasian States; variant 6 – proposed by Bystristkaya (1978); variant 7 – proposed by Lutikov (Aver'yanova et al. 1996) for the Chechen Republic; variant 12 – proposed by (Shebalin 2003).

Sometimes when other regional attenuation laws are accessible they are integrated into the Extremum System. There was the case of the 2006 Mozambique earthquake when Shebalin s equation gave an overestimation of shaking intensity and the Eq. 8.2 obtained on the basis of empirical data for the event in May 1940 (A. Kijko, personal communication) was used.

$$I_0 - I = a_1 - a_2 \ln(r) - a_3 r, \tag{8.2}$$

where a_1=1.4, a_2= –0.44, a_3= –0.0064, r is hypocentral distance in km, I is intensity and I_0 is the maximum intensity at the epicentre.

The circular isoseists obtained with Shebalin's equation application are stretched along the active tectonic faults in order to take into account anisotropy of the medium and source line extension. Expected shaking intensity maps are computed taking into account various regional coefficients of macroseismic fields, different orientation of ellipse axis, as well as empirical data on ratio k of the ellipse major and minor semi-axis (for different values of k). The empirical data on the dependency of major and minor semi-axis of an ellipse on magnitude M of an event and

Table 8.2 Dependency of ellipse axis size for isoseists of different intensity *I* on magnitude *M* and source depth *h*

		Isoseist of $I = 7$			Isoseist of $I = 8$			Isoseist of $I = 9$		
M	h (km)	2a (km)	2b (km)	k	2a (km)	2b (km)	k	2a (km)	2b (km)	k
5.5	10	10	40	4	5	10	2	–	–	–
6	10	22.5	70	3.1	7.5	20	2.7	2.5	15	6.0
6	20	25	70	2.8	10	22.5	2.25	5	15	3.0
7.5	10	55	173	3.1	27.5	112	4	11	61	5.54
7.5	15	70	173	2.5	35.6	112	3.15	15	61	4
7.5	30	61	214	3.5	65	125	1.9	26	71	2.7
8.1	22.5	143	286	2	81.25	175	2.15	38	100	2.6
8.1	40	450	900	2	212.5	500	2.35	100	300	3

source depth *h*, obtained by Mirzoev (Mirzoev and Dzhuraev 1985) for Central Asia could be used for some other regions. Table 8.2 shows the dependency for isoseists of different intensity *I*.

The uncertainties introduced by simulation models used for shaking intensity estimation could be reduced by the accumulation of new empirical macroseismic data, which allows the verification of regional peculiarities. In future, by collecting new data and improving the interpretation, new simulation models could be developed.

8.1.2 Vulnerability Functions for Buildings/Fragility Laws

In the present situation both concepts of fragility and vulnerability are used by the authors. Vulnerability may be estimated through physical and economic domains. Physical vulnerability is an index, which characterises the loss of functional properties of the structure being considered. It may be estimated as a ratio between the expected number of damaged buildings of a certain type due to earthquakes with intensity *I* and the total number of buildings belonging to this type. Economic vulnerability for buildings of different types is characterised by the ratio between the cost of repair and the initial cost of construction (Larionov et al. 2003a, 2003b; Larionov and Frolova 2006; Frolova et al. 2003a, 2007).

In the Extremum family system, the fragility laws used for different building types classified according to the MMSK-86 scale (Shebalin et al. 1986):

- Building type A (from local materials)
- Building type B (brick, hewn stone or concrete blocks)
- Building type C (reinforced concrete, frame, large panel and wooden)
- Building types E7, E8, E9 (designed and constructed to withstand earthquakes with intensity 7, 8, 9)

The expert estimation of different building types according to MMSK-86 and EMS-92 was undertaken in order to have the possibility of comparison of different vulnerability functions (Table 8.3).

Table 8.3 Comparison of building vulnerability classes according to MMSK-86 and EMS-92

	Vulnerability class	
Description of building types according to EMS-92	EMS-92	MMSK-86
Rubble stone, field stone	A	A
Adobe (earth brick)	A	A
Simple stone	B	A
Massive stone	C	B
Unreinforced (bricks/concrete blocks)	B	B
Unreinforced (brick) with RC floors	C	B
Reinforced or confined	D	C
Reinforced without earthquake-resistant design (ERD)	C	C
Reinforced with minimum level of ERD	D	E7
Reinforced with average level of ERD	E	E8
Reinforced with high level of ERD	F	E9
Timber structures	D	B-E7

The fragility laws are understood as the relationships between the probability of buildings belonging to different types being damaged and the intensity of shaking in grades of seismic scales. The laws are usually constructed on the basis of statistical analysis of strong earthquakes engineering consequences. There are two types of laws: the probability P_{Ai} (I) of damage state not less than a given value and probability P_{Bi} (I) of definite damage state. The normal law is used for constructing the curve approximating the probability P_{Ai} (I). The hypothesis about the normal law was checked with the application of the Kolmogorov-Smirnov criterion.

When constructing the fragility law, it is taken into account that buildings may suffer any damage state (from $d = 1$ up to $d = 5$) after an earthquake, namely a building after an earthquake may prove to be undamaged (event *B0*), to experience slight damage (event *B1*), moderate damage (event *B2*), heavy damage (event *B3*), to be partially destroyed (event *B4*) and completely collapsed (*B5*). In order to estimate the parameters for the model and derive a representative statistical data set, past events from the second half of the twentieth to the beginning of the twenty-first centuries in Russia, Uzbekistan, Turkmenistan, Romania, Moldova, Armenia, Georgia and other countries, was used. The values of mathematical expectation *M* of earthquake intensity in grades of MMSK-86 intensity scale, which result in a building damage state not less than a given value, are given in Table 8.4. The values of mean square deviations of intensity vary from 0.4 to 0.5.

When determining the probability P_{Bi} (I) of definite damage state, the theorem about the total group of events is taken into account

$$\sum_{i=0}^{5} P_{Bi}(I) = 1 \tag{8.3}$$

The probability $P_{Bi}(I)$ of definite damage state of buildings is estimated by the relationship

$$P_{Bi}(I) = P_{Ai}(I) - P_{Ai+1}(I) \tag{8.4}$$

Table 8.4 Averaged expected shaking intensity of earthquakes in grades of MMSK-86 scale, which will result in different damage states of buildings

Building types according to MMSK-86	Buildings damage states *d*				
	$d = 1$	$d = 2$	$d = 3$	$d = 4$	$d = 5$
A	6.0	6.5	7.0	7.5	8.0
B	6.5	7.0	7.5	8.0	8.5
C	7.0	7.5	8.0	8.5	9.0
*E*7	7.5	8.0	8.5	9.0	9.5
*E*8	8.0	8.5	9.0	9.5	10.0
*E*9	8.5	9.0	9.5	10.0	10.5

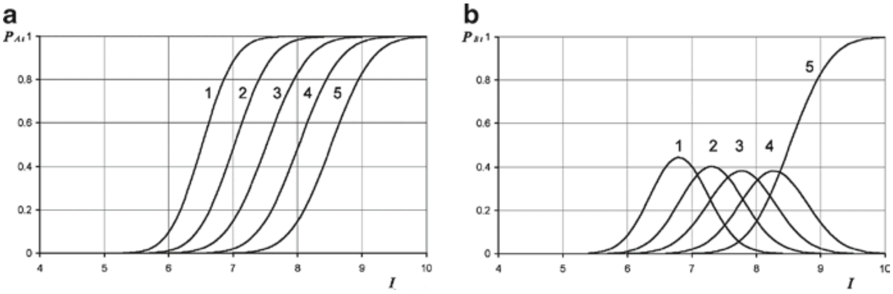


Fig. 8.2 Fragility laws for type *B* buildings (MMSK-86); (**a**) probability P_{Ai} (*I*) of damage state not less than given value; (**b**) probability P_{Bi} (*I*) of definite damage state; 1, 2, 3, 4, 5 – building damage states

where P_{Ai} (*I*) is the probability that buildings will suffer the damage state not less than state *i*; P_{Ai+1} (*I*) is the probability that buildings will suffer the damage state not less than state *i*+ 1. The fragility laws for the buildings of type B, constructed taking into account the characteristics of normal laws parameters given in Table 8.2 and $\sigma = 0.4$–0.5 are shown in Fig. 8.2.

Building stock from one earthquake prone area to another is so varied (material, mode of construction) that the validity of any averaged fragility laws (vulnerability functions) is questionable. And, in principle, it is desirable to rely on regional data sets when constructing the fragility laws (vulnerability functions), but relevant data are not available for all earthquake prone areas either because engineering data on consequences of strong earthquakes are not accessible or simply do not exist.

8.1.3 Vulnerability of Population/Laws of Earthquake Impact

Vulnerability of the population to seismic action at a given intensity is understood here as the ratio between the expected fatalities and the total number of persons living in a certain type of building. In order to estimate the mathematical expectation of fatalities and injuries within the built environment the laws of earthquake impact on population are used. They are understood as the dependency between the probability to be killed or/and injured and the intensity of shaking in grades of seismic intensity scales.

The parametric laws of earthquake impact on people inside buildings are constructed on the basis of analysis of empirical data about social losses during past strong earthquakes taking into account the theorem about the total group of events. When computing the laws, it is assumed that the event C_k (total number of social losses, irrevocable losses and injured) may occur providing that the building survived one of the damage states (at one of the hypotheses B_i forming the total group of incompatible events).

Fatalities and missing are referred to as irrevocable losses. The injured include all people who need medical treatment. The sum of numbers of injured and irrevocable losses is called total social losses. The structure of injury levels takes into account three levels of impact: extremely seriously injured, seriously injured and slightly injured. Social losses are computed according to

$$P_{Ck}(I) = \sum_{i=1}^{5} P_{Bi}(I)\, P(C_k \,|B_i) \tag{8.5}$$

where P_{Ck} (I) is the probability of people being impacted during the earthquake with intensity I; P_{Bi} (I) is the probability of definite i damage state of buildings providing the given value of earthquake intensity; P ($C_k|B_i$) is the probability of people surviving k level of impact under the condition that the building survived the damage state i. The values of P ($C_k|B_i$) are obtained on the basis of processing of empirical data

Table 8.5 Probability of population being affected for different damage states *d* of buildings

Social lossesC_k	Probability of population being affected at damage states of buildings *d*				
	d =1	*d* =2	*d* =3	*d* =4	*d* =5
Total	0	0.01	0.11	0.6	0.97
Fatalities	0	0	0.02	0.23	0.6
Injured	0	0.01	0.09	0.37	0.37

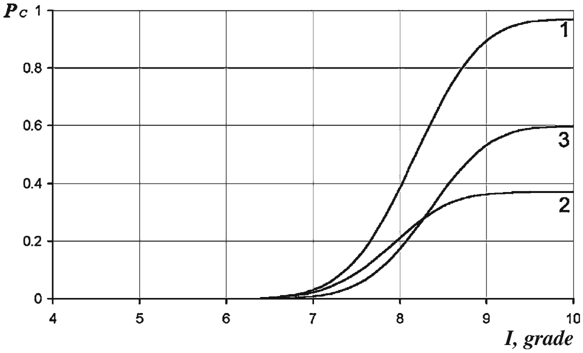


Fig. 8.3 Laws of earthquake impact on people inside type *B* buildings: 1-total social losses (total number of casualties); 2- injured; 3- fatalities

Table 8.6 Probabilities*PCk(I)*of population being affected inside buildings of different types against seismic intensity

MMSK-86 types	Social losses	Intensity in grades of MMSK-86 scale 6	7	8	9	10	11	12
A	Total losses	0.004	0.14	0.70	0.96	0.97	0.97	0.97
	Fatalities	0	0.05	0.38	0.59	0.6	0.6	0.6
B	Total losses	0	0.03	0.39	0.90	0.97	0.97	0.97
	Fatalities	0	0.01	0.18	0.53	0.6	0.6	0.6
C	Total losses	0	0	0.14	0.70	0.96	0.97	0.97
	Fatalities	0	0	0.05	0.38	0.59	0.6	0.6
E7	Total losses	0	0	0.03	0.39	0.90	0.97	0.97
	Fatalities	0	0	0.01	0.18	0.53	0.6	0.6
E8	Total losses	0	0	0.004	0.14	0.70	0.96	0.97
	Fatalities	0	0	0	0.05	0.38	0.59	0.6
E9	Total losses	0	0	0	0.03	0.39	0.90	0.97
	Fatalities	0	0	0	0.01	0.18	0.53	0.6

about social losses due to past events in the Commonwealth of Independent States (CIS) and other countries over approximately the last 50 years (Table 8.5).

The laws of earthquake impact on population inside buildings of type *B*, which are constructed with the use of Table 8.5, are shown in Fig. 8.3.

In Table 8.6 the probabilities of the population being affected against the seismic intensity *I*, which are obtained using Eq. 8.5 and Table 8.5, are shown.

While computing expected social losses the empirical data about the population migration during day time, as well seasonal variation, are also taken into account.

8.2 Extremum System Loss Estimations in Emergency Mode at Worldwide

Different Extremum family systems are used for expected loss assessment due to a strong earthquake at the worldwide. Since August, 2000, the system version has been used in order to provide quick information on damage and casualty assessment of strong earthquakes all over the world within the framework of EUR-OPA Major Hazards Agreement Program EDRIM (Electronic Discussion for RIsk Management).

Procedures for expected damage and loss assessment in emergency mode includes:

1. The information about the earthquake parameters (origin time, epicentre coordinates, depth, magnitude) is received by e-mail messages or taken automatically from websites of seismological surveys: Geophysical Survey of Russian Academy of Sciences (GS RAS), European Mediterranean Seismological Centre (EMSC), National Earthquake Information Center of USGS (NEIC), and occasionally national agencies, such as Kandilli Observatory and Earthquake Research Institute (KOERI), Japan Meteorological Agency (JMA), Japan Weather Association (JWA) and others

2. Computations of the extent of the expected damage, social and economic losses due to earthquakes and identification of the effective response measures
3. Expert estimation of the results obtained with the help of the knowledge base about past events
4. Taking a decision about the estimation of the expected consequences
5. Dissemination of messages about expected damage and losses

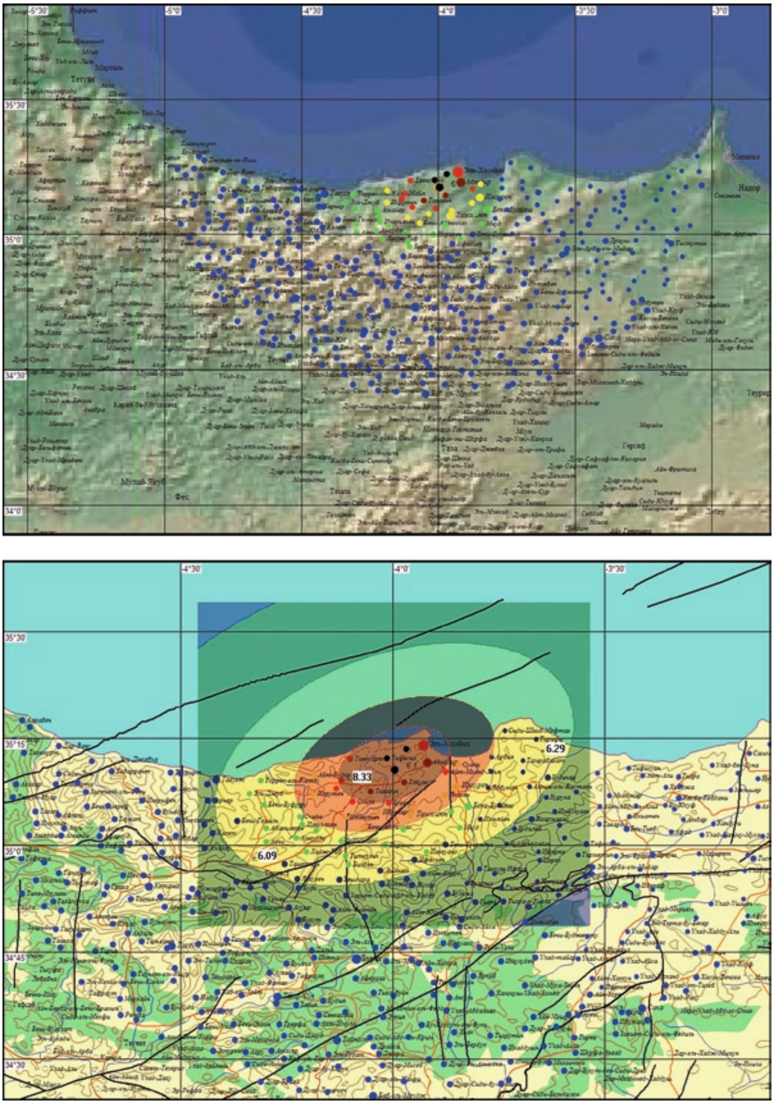


Fig. 8.4 Results of assessments of possible losses due to 24 February, 2004 earthquake in Morocco in different scales; *dots* are settlements in the stricken area; *colour of dots* stands for the average damage state of building stock: black -total collapse, brown–partial collapse, red–heavy, yellow–moderate, green–slight damage, blue–no damage; figures on the lower map are the values of expected shaking intensity

The results of computations are usually presented as maps and tables, where estimations of expected number of fatalities, injuries and homeless are given for the whole stricken area and for each settlement. Figure 8.4 shows maps with the results of expected damage and loss computation for the earthquake which occurred on 24 February, 2004 in Morocco with the application of the Extremum System. The settlements in the stricken area are shown by dots of different size and colour; the dot size stands for the number of inhabitants whilst the dot colour stands for the average damage state of the buildings. In the given example the computations were made for the following event parameters: Latitude – 35,190N; Longitude – 3,996W; Depth – 2 km; Magnitude – 6,1 (Cherkaoui and Harnafi 2004).

The results of expected damage and loss estimations strongly depend on the input event parameters determined by seismological surveys in emergency mode. Figure 8.5a, b show the patterns of expected damage distribution in the case of the Bam, Iran earthquake which occurred on 26 December, 2003, which were obtained using NEIC data (Fig. 8.5a) and IIEES data (Fig. 8.5b). Underestimation of expected damage was related mainly to unreliable depth determination (given as 33 km by GS RAS and NEIC and revised on 27 December, 2003) and to the uncertainty in event location (Table 8.7). According to the information published on 22 July, 2004 on the

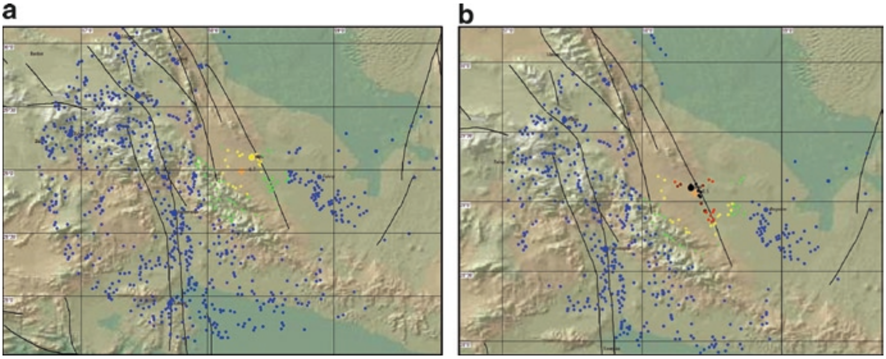


Fig. 8.5 (**a**) Results of assessments of possible losses due to 26 December, 2003 earthquake in Iran using NEIC event parameters. (**b**) Results of assessment of possible losses due to 26 December, 2003 earthquake in Iran using IIEES event parameters

Table 8.7 Expected consequences due to the Bam earthquake on 26 December, 2003

Survey	Coordinates	*M*	*h*km	Expected fatalities	Expected injured
NEIC	58.27 N; 29.01 E	6.7	33	18–221	110–1,008
NEIC, Significant Earthquakes	58.311 N; 28.995	6.6	10	5,538–22,337	14,933–40,904
EMSC	58.34 N; 29.05 E	6.8	30	1,201–6,939	2,751–18,661
GS RAS	58.38 N; 29.24 E	6.8	33	417–3,168	1,247–10,776
IIEES	58.38 N; 29.08 E	6.5	13.2	6,795–25,035	19,085–38,122
IIEES	58.38 N; 29.08 E	6.5	8[a]	11,022–35,394	33,067–40,831

[a] (Eshghi and Zare 2003)

ReliefWeb site the Iranian authorities revised the number of dead from the 26 December 2003 quake, which Bam officials had earlier said killed 43,000. The event location made by IIEES (assumed to be the most accurate) and focal depth estimation the by reconnaissance team (Eshghi and Zare 2003), allowed the estimation of the expected number of casualties to be closer to the reported one (Table 8.7).

Taking into account the scatter in the expected number of casualties obtained using different event parameters determined by seismological surveys in emergency mode, the role of experts should be mentioned. Expert knowledge and/or knowledge-base about past events in the stricken area may help to make a proper choice between the estimations on expected damage and loss obtained with the Extremum System application. In the case of Iran, the knowledge base about well-documented for past strong earthquakes includes 64 events (for the whole of Iran) with a description of their consequences (Fig. 8.6).

The analysis of results of computation on expected damage and loss by the expert team definitely allows the reliability of estimations to increase, which will be transferred to decision-makers. But it will take additional time and may result in a delay of about 1 h.

At present in order to avoid overestimation of losses with the Extremum System simulation model applications, empirical relationships between the number of casualties and earthquake magnitudes and intensity are used which are based on data for more than 1,000 earthquakes with M ≥ 3, characterised by anomalous high macroseismic effect, from the past to the present (Aptikaev and Frolova 1998). The areas where these effects were observed were conditionally divided into two categories: the first one, where most buildings and structures were designed and constructed

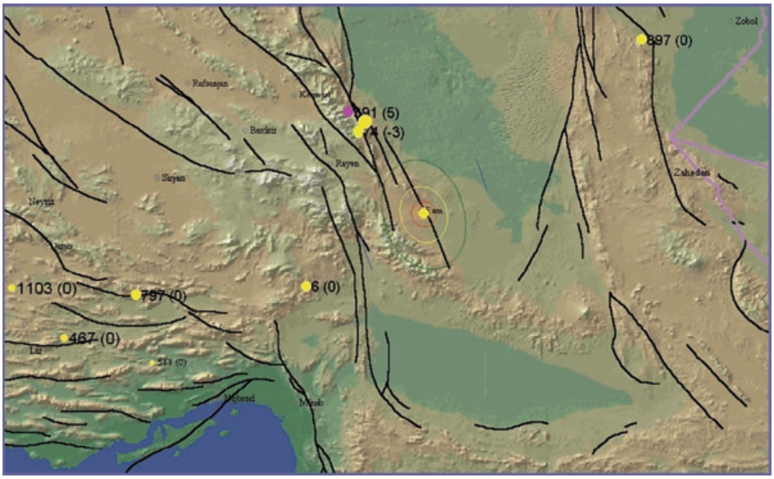


Fig. 8.6 Excerpt from knowledge-base map of epicentres of past events; values near epicentres are ordinal numbers of an event in the knowledge-base; values in brackets are errors in casualty estimation applying the Extremum system

accounting for seismic resistant measures, and the second one, where most buildings and structures were designed and constructed without earthquake resistant strengthening. The first group includes so called earthquake resistant countries and regions for the period after 1963: USA, Japan, Greece, Italy, the former Yugoslavia, Taiwan, Belgium, Germany, Netherlands, France, Czech Republic. The second group comprises the same countries for the period before 1963, as well as Argentina, Peru, Ecuador, Nicaragua, Salvador, Guatemala, Morocco, Egypt, Libya, Albania, Turkey (eastern part), Romania, Israel, Lebanon, Syria, Yemen, Iran, Iraq, Pakistan, India, China and the former USSR.

8.3 Use of Impact Database for Extremum System Calibration

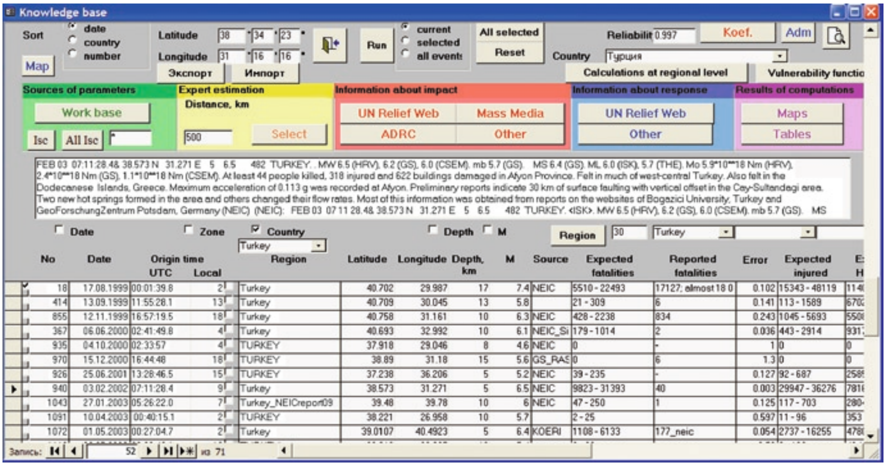
As was shown above, the "errors" in event parameter determinations by different seismological surveys contributes significantly to degrading the reliability of expected loss estimations. In order to estimate the influence of this factor, a special study has been carried out (Frolova 2003a). The study has shown that surveys could be ranked according to achieved accuracy within the different Flinn-Engdahl zones (Flinn and Engdahl 1965). As an outcome, the "right choice" of earthquake parameters may be made in emergency mode, taking into account weights assigned to each survey in the relevant Flinn-Engdahl zone. The weight is understood as the value inversely proportional to error in events parameter determinations in emergency mode as compared to parameters issued several days and months after events.

The uncertainty in loss estimations introduced by incompleteness of information about built environment and population distribution, as well vulnerability functions of different elements at risk may be compensated, to a certain extent, taking advantage of the system calibration exploiting the knowledge-base on well-documented past strong earthquakes (Frolova 2003b, 2006).

The procedure of the system calibration includes:

1. Collection of information about well-documented past earthquakes (event parameters, observed macroseismic effect, engineering analysis of consequences, information about resources and forces involved in emergency response)
2. Simulation of consequences for these events included in the impact knowledge-base
3. Comparison of computed and reported damage and casualties
4. Application of a special function in order to check the mathematical models' parameters
5. Estimation of residual errors in loss estimation

The special software has been created for earthquake impact data compilation, processing, analysis and storing. At present the knowledge-base contains the description of more than 1,500 events. The information about events source parameters, social, engineering and economic consequences, as well as response measures according to different sources is included in the knowledge-base. The main



Latitude 38° 34° 23°
Longitude 31° 16° 16°
Reliabilit 0.997
Country Турция
Distance, km 500

FEB 03 07:11:28.48 38.573 N 31.271 E 5 6.5 482 TURKEY. . MW 6.5 (HRV), 6.2 (GS), 6.0 (CSEM). mb 5.7 (GS). MS 6.4 (GS). ML 6.0 (ISK), 5.7 (THE). Mo 5.9*10**18 Nm (HRV), 2.4*10**18 Nm (GS), 1.1*10**18 Nm (CSEM). At least 44 people killed, 318 injured and 622 buildings damaged in Afyon Province. Felt in much of west-central Turkey. Also felt in the Dodecanese Islands, Greece. Maximum acceleration of 0.113 g was recorded at Afyon. Preliminary reports indicate 30 km of surface faulting with vertical offset in the Cay-Sultandagi area. Two new hot springs formed in the area and others changed their flow rates. Most of this information was obtained from reports on the websites of Bogazici University, Turkey and GeoForschungZentrum Potsdam, Germany (NEIC) (NEIC): FEB 03 07 11 28.48 38.573 N 31.271 E 5 6.5 482 TURKEY. <ISK>. MW 6.5 (HRV), 6.2 (GS), 6.0 (CSEM). mb 5.7 (GS). MS

☐ Date ☐ Zone ☑ Country Turkey ☐ Depth ☐ M Region 30 Turkey

No	Date	Origin time UTC	Origin time Local	Region	Latitude	Longitude	Depth, km	M	Source	Expected fatalities	Reported fatalities	Error	Expected injured	E H
18	17.08.1999	00:01:39.8	2	Turkey	40.702	29.987	17	7.4	NEIC	5510 - 22493	17127; almost 18 0	0.102	15343 - 48119	114
414	13.09.1999	11:55:28.1	13	Turkey	40.709	30.045	13	5.8		21 - 309	6	0.141	113 - 1589	670
855	12.11.1999	16:57:19.5	18	Turkey	40.758	31.161	10	6.3	NEIC	428 - 2238	834	0.243	1045 - 5693	550
367	06.06.2000	02:41:49.8	4	Turkey	40.693	32.992	10	6.1	NEIC_Si	179 - 1014	2	0.036	443 - 2914	931
935	04.10.2000	02:33:57	4	TURKEY	37.918	29.046	8	4.6	NEIC	0	-	1	0	0
970	15.12.2000	16:44:48	18	TURKEY	38.89	31.18	15	5.6	GS_RAS	0	6	1.3	0	0
926	25.06.2001	13:28:46.5	15	TURKEY	37.238	36.206	5	5.2	NEIC	39 - 235	-	0.127	92 - 687	258
▶ 940	03.02.2002	07:11:28.4	9	Turkey	38.573	31.271	5	6.5	NEIC	9823 - 31393	40	0.003	29947 - 36276	781
1043	27.01.2003	05:26:22.0	7	Turkey_NEICreport09	39.48	39.78	10	6	NEIC	47 - 250	1	0.125	117 - 703	280-
1091	10.04.2003	00:40:15.1	2	TURKEY	38.221	26.958	10	5.7		2 - 25		0.597	11 - 96	353
1072	01.05.2003	00:27:04.7	2	Turkey	39.0107	40.4923	5	6.4	KOERI	1108 - 6133	177_neic	0.054	2737 - 16255	478

Fig. 8.7 Excerpt of the impact knowledge base: the events are selected according to the dates of their occurrence

sources of information about reported losses are OCHA ReliefWeb, ADRC, NEIC and their links to mass media, as well as scientific publications and reports. The data in the knowledge base are distributed almost homogeneously as the losses due to earthquakes, dates of events and their locations are concerned. The software allows computations of possible losses to be made, to accumulate the results of computations in order to exclude gross errors in the descriptions of events. It also allows events to be selected according to their date, earthquake prone areas and number of event in the database. Figure 8.7 shows a fragment of the knowledge base. The selection of events is done according to the date of events. The arrow shows the earthquake, which occurred in Turkey on 3 February, 2002.

The developed knowledge base is used for the System calibration in order to compensate for the incompleteness of our knowledge about the built environment, population distribution, and regional vulnerability functions of elements at risk. The descriptions in the knowledge base are used as reference points. They allow the parameters of mathematical models to be determined by minimising the functional

$$\Omega = \sum_{i=1\ldots n} W_i \left(F_{ci}\left(p_1,\ldots,p_n\right) - F_{ri}\right)^2 \Rightarrow \min\left(p_1,\ldots,p_n\right) \tag{8.6}$$

where W_i – weights of events; F_{ci} – computed number of fatalities; F_{ri} – reported number of fatalities; $p_1,\ldots,p_n$ – free models parameters, used in the System.

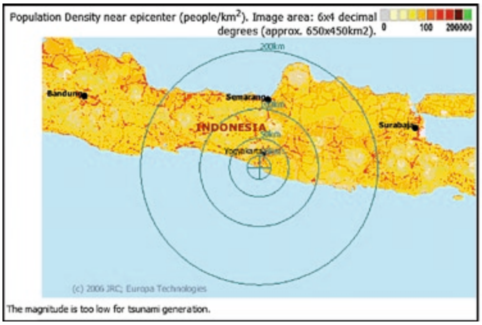
The current knowledge base has been used to compute the model parameters for earthquake prone areas of Russia and other countries all over the world.

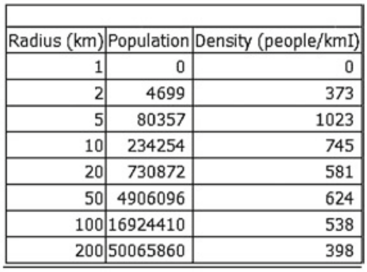
8.4 Extremum and Other Global Systems for Loss Estimations in Emergency Mode

At present, with the exception of the Extremum system there are two other global systems that allow the estimation of the scope of an earthquake disaster just after the event. They are: the Global Disaster Alert and Coordination System (GDACS) and the "Prompt Assessment of Global Earthquakes for Response" (PAGER) System.

GDACS has been jointly developed by the European Commission's Joint Research Centre and the United Nations Office for Coordination of Humanitarian Affairs (OCHA) since 2005. The main aims of the System are to alert the international community in case of major sudden-onset disasters and to facilitate the coordination of international response during the relief phase of the disaster (De Groeve 2006; De Groeve et al. 2008). The disaster alerts are based on automatic hazard information retrieval and real-time GIS-based consequence analysis. The GDACS earthquake impact model is built on the existing seismological infrastructure. Every 5 min GDACS collects information on rapid estimations of earthquake location, magnitude and depth of source from different agencies like NEIC, EMSC, GEOFON, JMA and others. By plotting the epicentre onto the map of population density GDACS estimates the population in the affected area within radii of different sizes. And it estimates the likelihood for need of international humanitarian intervention. Figure 8.8 shows a section of the alert event report for the earthquake in Indonesia on 26 May, 2006 from the web site of the system (http://www.gdacs.org).

The PAGER System of the US Geological Survey allows expected shaking intensity to be simulated by using the methodology and software developed for ShakeMap (http://earthquake.usgs.gov/shakemap). Then the expected number of inhabitants within the zones of different levels of shaking intensity *I* is estimated by using the information on population density from Oak Ridge National Laboratory's Landscan population database. PAGER is an automated system; it monitors the NEIC near-real-time detection of domestic and global earthquakes and issues alarms to emergency agencies and other end-users at national and international levels. Its estimations of population exposed could be verified as subsequent information about event parameters becomes available and a new alarm can then be issued. Figure 8.9 shows an example of the esti-





Radius (km)	Population	Density (people/kmI)
1	0	0
2	4699	373
5	80357	1023
10	234254	745
20	730872	581
50	4906096	624
100	16924410	538
200	50065860	398

Fig. 8.8 Results of possible impact estimation following the 26 May, 2006 earthquake in Indonesia

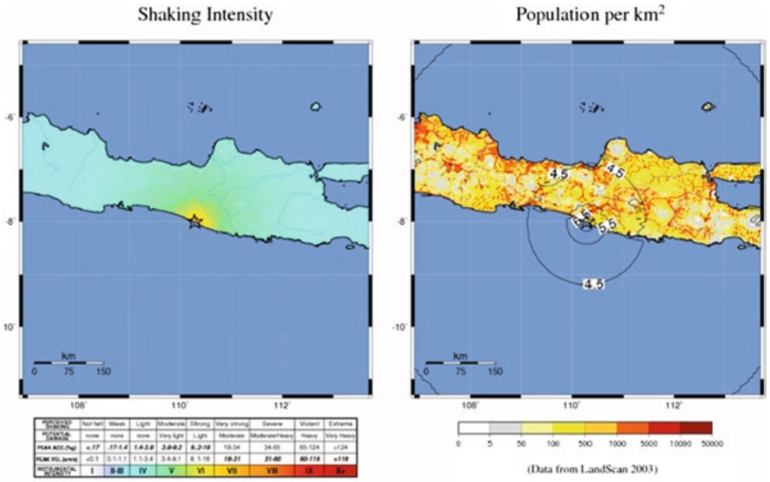


Fig. 8.9 Results of the estimation of possible consequences following the 26 May, 2006 earthquake in Indonesia with application of PAGER system

mation of possible consequences following the 26 May, 2006 earthquake in Indonesia. The number of population exposed to shaking was estimated as the following: for I = VIII – 8,000; for I = VII – 558,000 and for I = VI – 2,780,000.

At present the PAGER team is developing and testing a more comprehensive version of the System which includes the simulation models for casualty assessment (Wald et al. 2008a; Jaiswal et al. 2009b). It is planned that different models from fully empirical to largely analytical approaches will be used for the simulation of casualties.

The reliability of quick expected loss estimations with Extremum and other systems simulation applications is hampered by many factors such as lack of reliable data on elements at risk (population and built environment) and hazard sources; lack of reliable regional vulnerability functions for different elements at risk caused by earthquakes and secondary hazards; discrepancies in strong earthquake parameters determination by different alert surveys and lack of access to confidential sources of information. But the most important issues are the databases on population and building stock distribution, as well as regional vulnerability functions of various elements at risk and regional shaking intensity attenuation laws (Bonnin et al. 2002a, b; Bonnin Frolova 2004; Chen Yong et al. 2001; Frolova et al. 2006).

At present, efforts are under way in order to update the information about existing building stock with global coverage within the Extremum System and collect information about building distribution, collapse and fatality rate within the PAGER project (Wald et al. 2008a; Jaiswal et al. 2009b) by collaborative efforts with Earthquake Engineering Research Institute (EERI)'s World Housing Encyclopedia (WHE,http://www.world-housing.net).

Table 8.8 shows the outputs of three global systems for two strong events. Taking into account that according to OCHA Situation Report No.2 issued on 28

Table 8.8 Outputs of three global systems in emergency mode due to two strong earthquakes in 2006

	Estimation of expected social loss/population exposures by different systems		
Event	Extremum	GDACS	PAGER
22 February, 2006, M = 7.5, Mozambique	Expected number of fatalities: 7–40, injuries: 20–240	Estimated population in zones: $R=10$ km: 1,870 $R=20$ km: 7,340 $R=50$ km: 36,370 $R=100$ km: 221,308	Estimated population in zones: $I=$X: 1,000 $I=$IX: 8,000 $I=$VIII: 32,000
26 May, 2006, M = 6.2, Indonesia	Expected number of fatalities: 950–6,100, injuries: 2,500–20,000	Estimated population in zones: $R=10$ km: 234,254 $R=20$ km: 730,872 $R=50$ km: 4,906,096 $R=100$ km: 16,924,410	Estimated population in zones: $I=$VIII: 8,000 $I=$VII: 558,000 $I=$VI: 2,780,000

February, 2006 four people were killed and 36 were injured during the Mozambique earthquake and according to the SwissRe Annual Report, the number of fatalities due to the event in Indonesia was reported as 5,778, a certain *"bonus"* can be given to the Extremum System which uses simulation models at all steps of the estimation of the consequences of earthquakes, from modelling of shaking intensity distribution to different types of building behaviour during shaking of different intensities, to estimation of number of fatalities and injuries in collapsed and damaged buildings.

8.5 Future Research Needs

At present much effort should be undertaken to analyse the readily accessible impact databases with global, regional, sub-regional, and national coverage and to determine the current status regarding the accessibility, completeness, quality and reliability of impact data on damaging earthquakes; general formats and methods for impact data accumulation, as well as definitions used in the field, should be developed; development of software in order to accumulate and analyse information about well-documented past earthquakes: source parameters of events, macroseismic effects, engineering consequences, social and economic losses, as well as response measures, should be initiated; development of an international distributed knowledge-base on the physical and socio-economic consequences of damaging earthquakes should be initiated; as well as the mechanism for access requirements and activities dealing with knowledge base maintenance should be identified.

8.6 Conclusions

This chapter gives the description of simulation models for shaking intensity distribution, seismic vulnerability of different elements at risk, as well as methodological procedures for seismic risk assessment with application of the Extremum family systems.

The examples of the Extremum System application for damage and loss assessment in emergency mode worldwide, as well as a comparison of expected loss estimations by Extremum and other global systems are given.

On the whole, application of Extremum family systems for expected loss and risk assessment at different levels showed good and less good aspects for many reasons. In future, refinements should be introduced in order to avoid existing limitations in simulation models and databases on population and built environment distribution. They will be taken into account in the web version of the Extremum System, which is now under development. This new web tool will be useful for researchers and practitioners involved in seismic risk management.

Acknowledgments The authors would like to express their gratitude to the Earthquake Planning and Protection Organisation of Greece (OASP) and the Institute of Engineering and Earthquake Resistant Construction in Thessaloniki (ITSAK) for kindly providing seismic vulnerability data for buildings in Greece as well as to EERI and USGS who are responsible for the PAGER project.

Chapter 9
Estimating Casualties for the Southern California ShakeOut

K. Shoaf and H. Seligson

Abstract Casualty estimation methodologies generally provide estimates of injuries in categories that are not ideal for healthcare preparedness efforts. In order for healthcare planners to make use of casualty estimates, the results must be developed in a format that provides them with information on the types of resources that might be required for treatment. This paper describes the various casualty models used to estimate injuries and deaths that might occur in the M7.8 "ShakeOut" Scenario on the San Andreas Fault in Southern California, using a recommended, medically meaningful, categorisation scheme.

9.1 Background

The Great Southern California ShakeOut was a week of events with more than five million people practising what they would do in the event of a large earthquake on the southern portion of the San Andreas Fault. The event started as a component of the United States Geological Survey's Multi-Hazard Demonstration Project in Southern California, a project designed to identify the impacts of the multiple hazards that confront Southern California. As the project took shape, hundreds of scientists and engineers lent their expertise to model the effects of a plausible magnitude 7.8 earthquake from the beginning of the rupture through to the effects on the buildings, infrastructure, people, and the economy, as well as the resulting actions of the first responders, government agencies, non-governmental organisations,

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and Technological Hazards Research 29, DOI 10.1007/978-90-481-9455-1_9,

hospitals, businesses and the general public. This paper will describe the modelling of the health and medical impacts of this scenario earthquake event.

9.1.1 Southern California Shakeout

Disaster scenarios have many potential uses. They can be used to generate interest in a potential hazard. They can also motivate and help government officials, policy makers, responder organisations and the general public prepare, plan, and mitigate against a particular hazard. Their usefulness, however, is directly related to the validity of the scenario. Starting in 2006, a group of scientists at the United States Geological Survey (USGS) began to work on a scenario for the southern portion of the San Andreas Fault. The scenario was eventually used as the basis for one of the largest earthquake drills ever held in the United States that had people from all walks of life participating. Participants ranged from the Governor of California to local school children. They participated in an exercise that was unique not only in its size, but in the validity of the scenario from which it was derived. That scenario was developed by more than 150 scientists and engineers including seismologists, geotechnical engineers, structural engineers, civil engineers, planners, sociologists, public health scientists, psychologists and economists. These scientists worked together over 18 months to ensure a scenario that was often at the cutting edge of the fields they represented and was based in science from the beginning of the rupture of the fault, to the physical, social, psychological and economic impacts of the event on the population.

9.1.1.1 The Earthquake

The ShakeOut scenario earthquake is a magnitude 7.8 earthquake on the southernmost 300 km (200 mi) of the San Andreas Fault, between the Salton Sea and Lake Hughes. The extent of the fault rupture in this earthquake was determined from geological characteristics, after considerable discussion among geological experts. The rupture began at the southern end of the San Andreas Fault and ruptured to the northwest. The sudden rupture of a fault produces shaking as one of its effects. The ground motions were estimated with physics-based computer simulations of the earthquake with computer systems developed by the Southern California Earthquake Center Information Technology Research Program (Jones et al. 2008).

The major losses for this earthquake include building damage (including both structural and non-structural damage, as well as damage to building contents), damage to lifelines and infrastructure, and fire losses. The total financial impact of this earthquake is estimated to be about $200 billion with more than 250,000 households estimated to be displaced from their homes. Furthermore, all lifelines in the eight county region are estimated to be significantly impacted by the event. This includes disruption to the transportation network, electricity, water, and telecommunications. Overall casualty estimates include approximately 1,800 deaths and more than 50,000 individuals needing some level of medical care for injuries.

9.2 Estimating Casualties for the ShakeOut

Casualty estimation methodologies generally provide estimates of injuries in categories that are not ideal for healthcare preparedness efforts. In order for healthcare planners to make use of casualty estimates, the results must be developed in a format that provides them with information on the types of resources that might be required. At a minimum this information should include the types of injuries (or the mechanism of the injury) and the level of care required. Figure 9.1 shows the different levels of care that were required to treat injuries caused by the 1994 Northridge Earthquake (Seligson and Shoaf 2003); in the ideal situation, these injury categories would be identified in scenario casualty estimates. Additionally, information for healthcare planners would describe if the injuries were predominately blunt force trauma, crushing trauma, burns, or piercing trauma. The source of these mechanisms would help planners to identify specific healthcare resources that would be needed such as burn beds or suture materials.

In order for the ShakeOut casualty estimates to be as complete and scientific as possible, a number of different studies were undertaken. These included using modified HAZUS® results based on empirical data from the Northridge Earthquake,

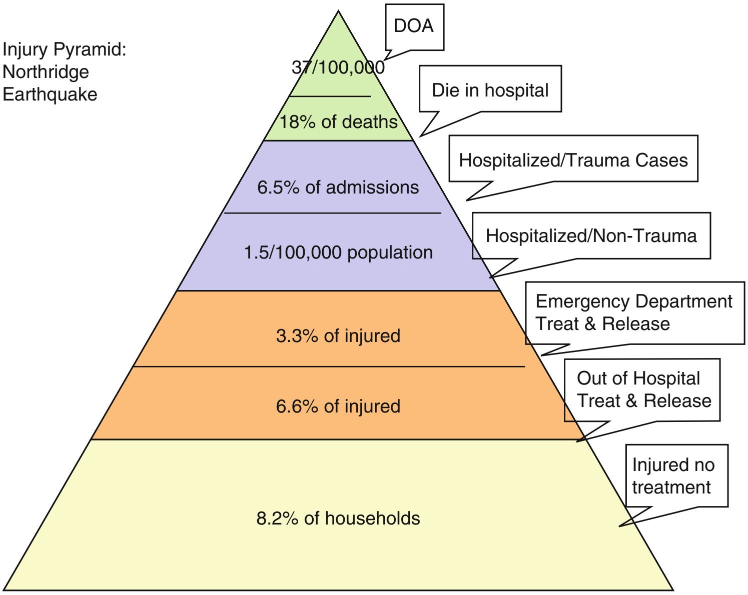

Fig. 9.1 Injury pyramid (Seligson and Shoaf 2003)

using an empirical model to estimate casualties from tall buildings, and creating models for estimating casualties from fires and transportation incidents from the available literature.

9.2.1 HAZUS®

HAZUS®, developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS), is a standardised, nationally applicable earthquake loss estimation methodology implemented through PC-based Geographic Information System (GIS) software. HAZUS® provides the capability to estimate scenario earthquake impacts, including both economic losses and population impacts, such as casualties and shelter requirements. HAZUS® uses four severity levels to categorise injuries, as given in Table 9.1 (NIBS and FEMA 2003).

HAZUS® has been used extensively in the development of earthquake scenarios and the estimation of associated regional impacts. For the ShakeOut scenario, MMI Engineering implemented significant HAZUS® database enhancements for the eight ShakeOut counties,[1] including improvements to the underlying building inventory data as well as to information utilised by HAZUS® on construction patterns throughout the eight-county study area. These data include inventory data calibrated to reflect available information on unreinforced masonry buildings tabulated by the California Seismic Safety Commission, a detailed database of buildings in Los Angeles County derived from Assessor's data, and construction

Table 9.1 HAZUS®-MH's injury classification scheme (Table 13.1, NIBS and FEMA 2003)

Injury severity level	Injury description
Severity 1.	Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are: a sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness. Injuries of lesser severity that could be self-treated are not estimated by HAZUS®.
Severity 2.	Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are third degree burns or second degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration or exposure.
Severity 3.	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. Some examples are: uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome.
Severity 4.	Instantaneously killed or mortally injured.

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[1] The eight "ShakeOut" counties include Imperial, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego and Ventura counties

type distributions that reflect building density concentrations in urban core areas as well as construction pattern changes over time throughout the eight counties. HAZUS® results for the ShakeOut scenario were used to directly estimate economic damage to buildings and their contents, quantify debris generated by ground shaking and building damage, and as input data to the ensuing direct and indirect regional economic analyses.

The most complete data on casualties in a U.S. earthquake are from the 1994 Northridge earthquake in California, and are derived from a number of sources:

- Coroner's reports of fatalities
- Medical records of persons admitted to hospitals in Los Angeles County
- Medical records from a sample of persons treated in Los Angeles County emergency departments
- Emergency department logs from a sample of area hospitals
- Telephone interview data from a random sample of households in Los Angeles County

This comprehensive data set allows for the examination of the number of injuries and deaths, the type and severity of those injuries, risk factors associated with being injured, the level of treatment required for those injuries, and the relationship between casualties and building damage. These data have been used to construct the injury pyramid shown in Fig. 9.1 that shows the relative values of the different injury severity levels.

These data may be used to calibrate engineering-based casualty models, such as those contained within FEMA's HAZUS® software, or the earlier EPEDAT software utilised in southern California (see Seligson amd Shoaf 2003). A calibration of HAZUS® casualty estimates for the Northridge earthquake was conducted to suggest "after-market" modifications for use in the ShakeOut scenario. The resulting model translates estimates of injuries and deaths in HAZUS®' four generalised categories to estimates of fatalities (non-hospital fatalities, i.e., DOA and fatalities requiring hospital care, i.e., ICU), trauma cases, non-trauma hospital admissions, emergency room treat and release, and out-of-hospital treatment. In addition, a model estimating the required number of EMS transports was also developed. Together, these represent the most important casualty categories for medical response planning. Because casualties suffered during the 1994 Northridge earthquake have been well documented, these data represent the best opportunity to validate and refine the casualty models implemented within regional loss estimation tools, such as HAZUS®.

In the calibration exercise, HAZUS® casualty estimates for the Northridge earthquake were derived using "state-of-the-practice" software and data:

- Latest available HAZUS® version – HAZUS®-MH MR-3, with Patch 1 installed
- Final USGS ShakeMap for the Northridge Earthquake
- Improved building inventory for Los Angeles County (derived from Assessor's data)
- Enhanced mapping schemes developed for the ShakeOut scenario

Table 9.2 Recommended HAZUS® casualty model modification factors developed from data on the 1994 Northridge earthquake

Injury category	Recommended casualty model	Modification factor for counties with improved inventory data (i.e., derived from assessor's data)	Modification factor for counties using HAZUS® default general building stock inventory data
1. Fatalities	F1 × (HAZUS® Severity 4)	F1 = 1.75	F1 = 2.09
2. Injuries Requiring Trauma Care	F2 × (HAZUS® Severity 3)	F2 = 0.27	F2 = 0.22
3. Hospitalised Non-Trauma Injuries	F3 × (HAZUS® Severity 2 + HAZUS® Severity 3)	F3 = 0.18	F3 = 0.15
4. Emergency Department (ED) Visits	F4 × (HAZUS® Severity 1 + HAZUS® Severity 2 + HAZUS® Severity 3)	F4 = 1.33	F4 = 1.2
5. Outpatient Injuries	F5 × (HAZUS® Severity 1)	F5 = 3.01	F5 = 2.75
6. Injuries Requiring EMS Transport	F6 × (HAZUS® Severity 2 + HAZUS® Severity 3)	F6 = 0.43	F6 = 0.36

The HAZUS® results were compared to the actual casualty statistics to develop modification factors translating HAZUS®' four injury severity estimates into the more medically-meaningful injury pyramid categories, following the procedure developed in (Seligson and Shoaf 2003). Two versions of the modification factors was developed; one set for Los Angeles County (where replacement inventory data were available), and one set for the remaining counties (where improved inventory data were not available), generated using state of the practice data with default inventory data substituted for the improved inventory data. The resulting modification factors are provided in Table 9.2.

It should be noted that the application of the modification factors for the ShakeOut scenario assumes that injury patterns in the larger ShakeOut scenario would be similar to those seen in the moderate Northridge earthquake, and that building vulnerability in the eight counties impacted by the ShakeOut scenario would be similar to that in Los Angeles County (a reasonable assumption, except for unreinforced masonry construction which is more likely to have been retrofitted in Los Angeles and Orange counties than in the remaining ShakeOut counties). Both of these factors may lead to an underestimation of the casualties. Nevertheless, it is expected that casualties estimated using the modification factors, while not matching casualty patterns precisely, will provide a reasonable order-of-magnitude estimate of deaths and injuries. The resulting model provides injury estimates in a format consistent with injury data collected in the field that are meaningful and useful to medical professionals planning for and responding to disasters. The casualty estimates developed from the HAZUS® results and modification factors for the ShakeOut scenario (due to ground shaking only) are provided in Table 9.3.

Table 9.3 Casualties resulting from building damage due to ground shaking in the ShakeOut scenario earthquake (HAZUS® results)

County	Fatalities	Trauma	Non-trauma hosp.	ED	Outpatient
				Visits	
Los Angeles	66	16	98	4,100	7,700
Imperial	0	0	0	0	0
Kern	0	0	1	0	100
Orange	1	0	9	700	1,500
Riverside	61	15	105	4,100	7,400
San Bernardino	132	32	196	7,400	13,400
San Diego	0	0	0	0	0
Ventura	0	0	0	0	0
8-County Totals	260	63	409	16,300	30,100

Table 9.4 Injuries resulting from collapse of steel frame buildings in the ShakeOut scenario earthquake

County	Fatalities	Trauma	Non-trauma hosp.	ED	Outpatient
				Visits	
Los Angeles	242	65	107	315	242
Imperial	0	0	0	0	0
Kern	0	0	0	0	0
Orange	105	28	46	136	105
Riverside	0	0	0	0	0
San Bernardino	92	25	41	119	92
San Diego	0	0	0	0	0
Ventura	0	0	0	0	0
8-County Totals	439	117	194	570	439

9.2.2 *Injuries from Collapse of Steel Frame Buildings*

An engineering team from CalTech performed a special study of steel frame buildings and concluded that some collapse of steel frame buildings was likely in this scenario (Jones et al. 2008; Krishnan and Muto 2008). As the HAZUS® building damage models are not robust for very tall buildings (e.g., 20+ storeys), it was necessary to estimate the casualties for these buildings separately. The CalTech study theorised the collapse of five high rise steel frame buildings in the scenario event. These included three buildings in Los Angeles, one near Costa Mesa in Orange County and one in San Bernardino, with an overall occupancy of approximately 3,500 people. It was estimated that these collapses would result in 439 deaths and close to 900 injuries (Table 9.4).

No models exist for estimating casualties from the collapse of steel frame buildings. As reported in the Shakeout report (Jones et al. 2008), significant damage to steel frame buildings has only been identified in three earthquakes: the 1985 Mexico City earthquake; the 1994 Northridge earthquake; and the 1995 Kobe earthquake.

Table 9.5 Injury rates (% of occupancy injured) by injury pyramid category in collapsed concrete buildings, 1999 Kocaeli Turkey earthquake

Level of building damage	Total collapse		Partial collapse		
Building height (storeys)	5–10	1–4	5–10	1–4	Total
Death on arrival (DOA)	12.7 (*n* = 33)	0.0 (*n* = 0)	2.0 (*n* = 3)	0.0 (*n* = 0)	7.0 (*n* = 36)
Died in hospital	0.4 (*n* = 1)	0.0 (*n* = 0)	0.0 (*n* = 0)	0.0 (*n* = 0)	0.2 (*n* = 1)
Hospitalised	3.5 (*n* = 9)	1.7 (*n* = 1)	0.0 (*n* = 0)	0.0 (*n* = 0)	1.9 (*n* = 10)
Hospital care: treat and release	5.8 (*n* = 15)	3.4 (*n* = 2)	0.0 (*n* = 0)	0.0 (*n* = 0)	3.3 (*n* = 17)
Out-of-hospital care: treat and release	17.0 (*n* = 44)	8.6 (*n* = 5)	7.4 (*n* = 11)	3.9 (*n* = 2)	12.0 (*n* = 62)
Injured but no treatment sought	10.0 (*n* = 26)	5.2 (*n* = 3)	8.7 (*n* = 13)	9.8 (*n* = 5)	9.1 (*n* = 47)
Not injured	50.6 (*n* = 131)	81.0 (*n* = 47)	81.9 (*n* = 122)	81.0 (*n* = 47)	66.5 (*n* = 344)
Total N	*N* = 259	*N* = 58	*N* = 149	*N* = 51	*N* = 517

Only the Mexico City earthquake resulted in collapse and casualties, but there is no documentation available for those casualties. The ShakeOut steel frame building casualty estimates were generated from a model derived for complete collapse of 5–10 storey non-ductile concrete buildings (Seligson et al. 2006). Table 9.5 shows the results of the study of casualties in concrete buildings in Turkey that served as the model for the steel frame collapse casualty estimates. We utilised the values for total collapse of buildings 5–10 storeys in height, which had the highest casualty rate in the study. Applying these findings to the estimated collapsed steel-frame buildings in the Shakeout, it is estimated that approximately 50% of occupants of these buildings would be injured, 13% of occupants of a collapsed building would die, and an additional 3.5% of occupants would require trauma care. As the study was conducted in Turkey, there was not a comparable trauma care system, so for the purposes of the shakeout, all hospitalised patients were assumed to require trauma care.

9.2.3 Injuries Resulting from Fire-Following Earthquake

Fire following earthquake can potentially be an important source of injuries in major earthquakes. The significant fires that resulted in the great Kanto earthquake and the 1906 San Francisco earthquake demonstrate the potential for fires and fire-related injuries. In recent time, we have not seen similar post-earthquake conflagrations, although there were smaller fires in the Loma Prieta earthquake, the Northridge earthquake and the Kobe earthquake. Of the approximately 5,500 deaths in the 1995 Kobe earthquake, about 10% resulted from burns.

For the Shakeout scenario, modellers proposed that there was significant potential for fires, including super conflagrations in dense urban areas. The modellers estimated the buildings in the areas of conflagration would be the equivalent of 133,000 single-family dwellings (Scawthorn 2008). To calculate the deaths and injuries resulting from the fires, the numbers of single-family-dwelling equivalents in the conflagration areas was used as the base for this estimation of casualties, because the fire locations are not specific enough to apportion other occupancy types. We make the assumption that the number of casualties in residences due to fire will, within the same order of magnitude, approximate the number in other occupancies. The populations exposed to the fire are assumed to be those who would be at home at 10:00 on a weekday morning (the time of the event). These are most likely mothers with young children and the elderly. Therefore, the exposed population was calculated by the percentage of households in each county represented by those sub-populations, multiplied by two per household for mothers with young children and 1.5 per household for the elderly.

Injuries and deaths from residential fires have decreased dramatically in the United States in the last few decades. The majority of this reduction is the result of the increased utilisation of smoke detectors and adequate fire suppression. In spite of this, people are still injured in residential fires. In 2006, fire departments responded to 412,500 home fires in the United States, which claimed the lives of 2,580 people and injured another 12,925 (Karter 2007). Increased risk for dying in a fire is attributed to young children, older adults, persons living in substandard housing, and persons living in rural areas (CDC Factsheet). Approximately 3% of residential fires in the United States result in an injury or death. In rural areas, the risk of injury or death is 2.7 times higher than the U.S. average, primarily due to fire department response times greater than 5 min (Flynn 2008). For each injury-causing fire, 51% result in mortality, 29% in significant injuries requiring specialised care (burn beds), and 39% in injuries treated in and released from an emergency department. It is expected that all burn injuries requiring hospitalisation will require specialised care, therefore non-trauma hospitalisation is zero. By multiplying these factors by the population exposed, an additional 916 deaths are added to the total and 564 more patients are seen in emergency departments for burn and inhalation injuries. Most important, these calculations result in more than 400 individuals requiring specialized burn care for burn and inhalation injuries. Many of these injuries may also be complicated by additional traumas (i.e., fractures, crush injuries, etc.) (Table 9.6).

9.2.4 Injuries Resulting from Impact to the Transportation System

Transportation-related injuries can add significant numbers of deaths and injuries in an earthquake. In a study of the Loma Prieta earthquake, Shoaf et al. (1998) found that approximately 25% of the injuries reported in a population survey resulted from transportation-related incidents. In the Northridge earthquake (Peek-Asa et al. 1998), about 10% of the deaths were associated with transportation

Table 9.6 Injuries resulting from fire-following earthquake in the ShakeOut scenario earthquake

County	Fatal	In patient (Trauma/ burn/ICU)	Emergency department
Los Angeles	647	292	398
Imperial	0	0	0
Kern	0	0	0
Orange	255	115	157
Riverside	8	4	5
San Bernardino	6	3	4
San Diego	0	0	0
Ventura	0	0	0
8-County Totals	916	414	564

incidents. The transportation injuries and deaths include those resulting from motor vehicle crashes due to stoplights being out, ground motion reducing driver control, as well as infrastructure damage (broken roadways, bridge failure, etc.).

Injuries for the ShakeOut scenario were calculated for two different mechanisms, motor vehicle crashes and earthquake-induced road/bridge damage. For motor vehicle crashes, the California Highway Patrols-Statewide Integrated Traffic Records System was used to estimate the expected number of crashes in the eight -county impact region for 10:00 on a Thursday in November. In unpublished data from a study on El Niño, the authors found that adverse conditions increase traffic crashes by approximately 10%. Therefore, the expected number of crashes (fatal and injury-inducing) was multiplied by 1.1 (Table 9.7).

An additional and important component adding to transportation casualties is the impact due to the damage to the freeway and bridge infrastructure. Three earthquakes in the late twentieth century (Loma Prieta, Northridge, and Kobe) demonstrated the potential for human loss from damage to the transportation system. Ideally, to calculate the numbers of casualties resulting from this type of damage, road and bridge sections would be identified by the type of damage estimated. Then it would be possible to calculate the exposure of individuals to the impact and extrapolate numbers of injuries. Unfortunately, those exact or estimated impacts were not developed in the scenario. However, the scenario mentioned that many sections of roadway and bridges in highly transited areas would be impacted by significant ground displacement as well as landslides and liquefaction. Given these impacts on highly transited roadways, it is expected that some casualties would occur. Due to the imprecise nature of the damage estimates, values for fatalities were estimated to be within an order of magnitude of the fatalities for the Loma Prieta, Northridge and Kobe earthquakes (for example, Northridge $n = 1$ or 3% of total; Loma Prieta $n = 46$ or 80% of total). Given the number of segments of highways and bridges damaged and the volume of traffic on those highways during the daytime, it was estimated that 150 deaths and 120 trauma cases would result.

Table 9.7 Injuries resulting from the transportation system in the ShakeOut scenario earthquake

County	Fatalities/highway damage	Inpatient (trauma) highway damage	Fatal crashes	Inpatient (trauma) crashes	ED crashes	Outpatient crashes
Los Angeles	100	80	3	13	381	762
Imperial	0	0	0	0	5	9
Kern	0	0	1	2	27	55
Orange	0	0	1	3	101	203
Riverside	0	0	2	4	70	140
San Bernardino	50	40	2	4	74	149
San Diego	0	0	1	4	102	205
Ventura	0	0	0	1	28	55
8-County Totals	150	120	11	31	789	1,578

Table 9.8 Total casualties resulting from the Shakeout scenario earthquake

County	Fatalities	Trauma	Non-trauma hosp.	ED Visits	Outpatient
Los Angeles	1,059	453	612	4,987	9,175
Imperial	0	2	1	5	9
Kern	1	13	5	27	155
Orange	362	146	185	1,005	1,995
Riverside	71	22	113	4,175	7,545
San Bernardino	282	103	406	7,519	13,672
San Diego	1	4	7	102	205
Ventura	0	1	2	28	55
8-County Totals	1,776	745	1,330	17,847	32,811

9.2.5 Total Casualties

Overall almost 1,800 fatalities are estimated for this earthquake in the eight-county region and more than 50,000 people are expected to be injured to an extent that they will require some level of treatment. These numbers (shown in Table 9.8) represent the best estimates of morbidity and mortality directly resulting from the scenario earthquake.

9.3 Discussion

The results presented in this paper are a divergence from the typical methodology for casualty estimation for earthquakes. Most casualty estimates are derived from models that estimate building damage, but few take into consideration the multiple contributors to injury. The approach taken in this paper includes casualty estimates from building damage from ground motion (using HAZUS® as the basis), but also includes additional sources of injury not included in the general casualty model of HAZUS®. It should be noted that as an initial attempt to estimate injuries from multiple causes, it was not possible in this study to correct for potential double-counting. That is, it is possible that fire-related injuries impacted people who would have already been assumed to have been injured in the ground shaking. Future development should consider ways to account for, and avoid such double-counting.

All of the calculations presented here could be improved by additional work. Some of the additional work required includes more accurate assessments of the damage leading to injuries. For example, a better estimation of the occupancy categories of the buildings in the conflagration would provide for better estimates of the population exposed and thus to more accurate injury estimates. On the other hand, more and better data are required to elucidate the role that various hazard impacts play in injury causation. For example, there are no data demonstrating the relationship between collapse in steel frame structures and casualties.

This chapter represents a first step in parsing out the various components that come to play in injury causation. Further research should continue into data collection efforts focusing on the relationship between different types of damage and casualties. Additionally, research efforts should be undertaken in a fashion that mirrors the interdisciplinary nature of casualty work.

Part III
Lessons Learnt from Regional Studies

Chapter 10
Casualty Estimation due to Earthquakes: Injury Structure and Dynamics

S. Goncharov and N. Frolova

Abstract The chapter describes the Russian experience in earthquake casualty estimation and organisation of medical support to the population in a stricken area. Based on empirical impact data caused by the 1948 Ashkhabad, 1967 Tashkent, 1988 Spitak, 1995 Neftegorsk earthquakes and others, a procedure was developed to assess the number of fatalities and injuries of different levels for three types of settlements. The procedure is able to take into account the dynamics of casualties through time and to identify different types of injuries. Examples of casualty estimations caused by scenario earthquakes in Petropavlovsk-Kamchatsky city are given, and organisational issues dealing with medical support and mass medical evacuation of the affected population within relief operations are considered.

10.1 Introduction

Statistical data on natural disasters and their consequences provided by international organisations and insurance companies show an increase both in the number of events and their negative impact. According to Swiss RE (SIGMA 2009) 97.7% of fatalities due to devastating catastrophes of natural and man-made character in 2008 resulted from natural disasters. The 12 May 2008 Wenchuan earthquake in China alone resulted in almost 70,000 people killed and over 374,000 injured.

The Russian Federation territory is subjected to wide range of hazardous natural phenomena and processes (geological, hydro-geological, meteorological and others). About 20% of the territory is located in earthquake-prone areas; and earthquakes with

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intensities of 8–9 (MMSK-86 scale) (Shebalin et al. 1986) occur within 5% of the country. More than 20 million people (14% of the population) are threatened by disastrous events. According to the map of individual seismic risk zonation for the country compiled with application of the "Extremum" system the values of risk (probability of death due to possible earthquake within 1 year in a given territory) vary from negligible up to 50.0×10^{-5} and higher. The highest values of risk are typical for settlements in Sakhalin, Kuril Islands, Kamchatka, near Lake Baikal, Altai-Sayan region and Northern Caucasus. In these regions special measures should be implemented to reduce the risk level.

Since the beginning of the 1990s in Russia much attention has been paid to high-technology strategies for coping with natural and technological emergencies, risk reduction, and disaster management. The strategy has been developed and implemented under special Russian Federal Programmes "Safety of Population, Buildings and Structures against Natural and Technological Hazards" and "Federal System of Seismological Observations and Earthquake Prediction". According to the national natural hazards risk reduction strategy, priority is given to preventive measures plan development and implementation. Much attention is also paid to search and rescue operations as well as other urgent measures in the case of emergency. Organisational issues of timely and effective medical support of affected population and evacuation are considered to be significant as well.

10.2 Procedures for Casualty Assessment due to Earthquakes

In the Military Engineering Academy named after Kujbyshev (Larionov et al. 1991) a procedure was developed to estimate the damage to buildings of different types classified according to MMSK-86 scale and the casualty rate in the damaged and collapsed buildings. In the All-Russian Centre for Disaster Medicine "Zazhita" in order to study regularities in the development of medical earthquake-related aftermath, the logical/mathematical simulation was undertaken for the following: structure of casualties and medico-evacuation pattern of the affected population; working conditions of medical units and facilities at the earthquake site; system of medical support in earthquake relief operations. 2,560 variants of earthquakes emergencies and corresponding medical response activities were studied (Shoju et al. 1998).

Empirical data on consequences and lessons learned from 1948 Ashkhabad, 1967 Tashkent, 1998 Spitak, 1995 Negnegorsk earthquakes as well as other strong earthquakes worldwide were used during the study. The results of the research showed that medical earthquake aftermath is determined primarily by an instantaneous appearance of a great number of victims with traumatic injuries. The number and structure of casualties among the population depend on seismic intensity and population location at the moment of the catastrophic event (in the open; in various buildings); the structure of traumatic injuries is also conditioned by the location of people at the moment of being injured. The coefficients of the number of injured were obtained for the cases when 100% of population or some proportion was housed. The number of casualties strongly depends on the time when search and rescue operations started. Table 10.1 shows an example of dynamics of casualties

Table 10.1 Changes in the number of injured in the case of earthquakes of different intensities and at different rate of rescue operations

Intensity of earthquake	Percent of injuries after a given time of extrication of the injured from the debris		
	3 days	6 days	10 days
8	99.8	99.7	99.6
9	97	96	94
10	95	93	94
11	86	82	68
12	78	73	53

Table 10.2 Expert estimation of possible fatalities among different groups of injured population

Time elapsed after the event, h/days	Proportion of fatalities within the groups of patients with different level of injuries		
	Seriously injured with life-threatening injuries	Seriously injured with injuries not threatening life	Light and moderate level of injuries
>6 h	60	–	–
6–12 h	20	–	–
13–24 h	10	–	–
25–48 h	7	–	–
49–72 h	3	10	–
4–6 days	–	60	20
7–10 days	–	20	75
11–12 days	–	10	5
Total	100	100	100

for earthquakes with intensities equal to 8–12 grades of MMSK-86 scale. Numbers of injured at the moment of earthquake are assumed to be equal to 100. In the case of an event with $I = 9$ and rescue operations lasting 3, 6 and 10 days, the number of fatalities correspondingly increases by 3%, 4%, 6%. In the case of an event with $I = 11$ the corresponding increase will be 14, 18 and 32.

Table 10.2 gives average expert estimations of the dynamics of the possible number of fatalities in the case of injuries of different levels of victims who are trapped under debris. The table shows that 60% of the affected population with life-threatening injuries dies in the first 6 h, and 80% in the first 12 h. The death of those having serious but not life-threatening injuries as well as light and moderate injuries is likely to occur within days. On the whole 50–55% of those people buried in the debris perish in the first 3 days.

Table 10.3 shows the expected structure of traumatic injuries for earthquakes with $I = 6, 8, 10, 12$, which is recommended for taking decision on quick response after the strong event. On the average the structure of injuries due to earthquakes could be estimated as follows: head – 19%, thorax – 8%, abdomen – 1%, pelvis – 5%, extremities – 52%, multiple – 11%.

Table 10.3 Expected proportion of traumatic injuries among total injuries

		Percent of injuries of definite type in the case of earthquakes with different *I*			
Injury position	Character of injuries	$I = 6$	$I = 8$	$I = 10$	$I = 12$
Head	Total	19.0	19.0	18.3	18.2
	Including bone injuries	0.6	1.3	3.3	3.6
Thorax	Total	8.8	8.5	7.7	7.6
	Including bone injuries	0.8	1.1	2.2	2.3
Abdomen	Total	1.0	1.0	1.0	1.0
	Including visceral injuries	0.004	0.07	0.2	0.2
Pelvis	Total	4.4	4.8	6.0	6.2
	Including bone injuries and urogenital organs	0.4	1.0	2.6	2.8
Spine	Total	3.4	3.8	5.0	5.2
	Including bone injuries	0.5	1.0	2.7	2.9
Extremities	Total	54.6	53.2	48.8	48.2
	Including bone injuries	5.2	7.5	14.9	16.0
	Including crush-syndrome	2.3	2.8	12.6	14.0
Multiple	Total	8.8	9.7	13.2	13.6
	Including crush-syndrome	0.6	1.3	3.3	3.6

Table 10.4 Medical evacuation indices of earthquake casualties recommended for quick response in % of all injuries

	Seismic intensity *I*	
Medical evacuation index (needs)	$I = 7–8$	$I = 9–10$
Antishock complex therapy	6.3	16.4
Operative intervention, including	8.3	21.7
Operations for emergency indications	1.2	3.1
Haemodialysis	2.0	5.3
Transport immobilisation	8.3	21.7
Punctures of pleural cavity	0.05	0.13
Novocaine blockade	5.0	13.1
Temporary hospitalisation due to patient non-transportability	6.8	17.1

The increase in seismic intensity from 6 to 12 results in a corresponding increase in the proportion of: pelvic injuries from 4.0% to 6.2%, spinal injuries – from 3.0% to 5.2%, multiple injuries – from 8.0% to 13.6%. At the same time all types of injuries become more severe. The comparison of injuries rate for events with $I = 10$ and $I = 6$ shows the increase of more than five times in the proportion of head injuries associated with damage to bones; increase of almost three times in the proportion of thoracic injuries with damage to bones; an increase of five times in the proportion of abdomen injuries with visceral damage; an increase of almost three times in the proportion of extremities with bone damage, and an increase of more than five times in the proportion of injuries with crush-syndrome.

Logistic planning of medical support and evacuation should take into account the increase of needs in the case of stronger events. Table 10.4 shows the recommended medical evacuation indices in the case of emergency.

Table 10.5 Indices of bed space demand for hospital treatment of earthquake -related casualties in % of injured among population and bed space structure

Type of medical facilities, profile	Seismic intensity *I*, grades of MMSK-86 scale				Proportion of beds for given medical profile, %
	6	8	10	12	
Neurosurgical (including patients with eye, ear, nose, throat, face and jaw injuries)	1.2	2.6	6.9	8.0	13
Thoracic-abdominal, urological	0.9	4.9	5.2	5.6	10
Trauma	2.4	4.9	13.3	15.2	26
Multiprofile (surgical)	1.6	3.2	8.6	9.9	17
General surgical	3.2	6.6	17.9	20.5	34
Total	9.3	19.2	51.9	55.9	100

The study undertaken allowed estimations of immediate medical support (complex of urgent medical-diagnostic, sanitary-epidemiological, medical-evacuation and other medical support within short period of time under the condition of life and health threatening injuries in a zone affected by an emergency) to be made for events with different intensity levels. For example, for 500 patients, this would include the provision of 3–6 physicians, 7–11 paramedics and experienced medical assistance at medical formations and a total of 11–22 physicians and 22–46 paramedics in organisations. A great number of injured patients could require hospital treatment (Table 10.5). If seismic intensity is estimated at 11–12, more than 50% of the injured patients require such treatment. In relation to the total amount of population the maximum need in hospital beds arises at $I = 9–10$. It is worthwhile to note that the given structure of hospital beds remains stable at different seismic intensities and various locations of the population.

As a result of the study the concept of a medical support system was developed. Its brief content is the following:

- In organisation and provision of medical support, disaster medicine should solve the following main tasks:
  - Participation in delivery of the first medical aid and in evacuation of casualties from the earthquake affected area; (general purpose emergency rescue teams should carry out the search for the injured, their extraction from the ruins, delivery of first medical aid on the site of the disaster and casualty clearing)
  - Organisation and delivering the emergency medical care to the injured patients at prehospital and hospital stages
  - Organisation of transportation of casualties within the stages of medical evacuation.
- All medical facilities of a given administrative region irrespective of their departmental subordination should be involved in medical emergency response to the victims of an earthquake.

- Medical support in earthquake relief operations should be organised and implemented as a chain of medical treatment of the patients with their evacuation to hospitals providing competent medical care. Depending on the type of an earthquake and the situation, medical measures of various types should be undertaken within relief operations.
- Medical facilities of a hospital type, which belong to the system of disaster medicine service in the zone of an earthquake, as well as special medical care teams, which belong to other medical facilities, usually operate for a period of 15 days; later the treatment of the disaster victims and their rehabilitation should be administered by the normal system of public health effective in this country.
- An effective dispatcher service and medical escort of the injured patients should be organised for evacuation and transportation of casualties.

10.3 Logistic Planning in the Case of Scenario Events in the Kamchatka

The Kamchatka area is one of the most seismically active regions of Russia and the world. It belongs to the Kuril-Kamchatka seismic zone, where earthquakes with magnitudes above eight are possible. According to the continuing long-term earthquake prediction study for the Kuril-Kamchatka island arc based on the pattern of seismic gap and the seismic cycle (Fedotov et al. 2007) the most likely locations of future M ≥ 7.7 earthquakes include Petropavlovsk-Kamchatsky city. The probability of such an event causing ground motions of intensity 7–9 in the city is 48% for 2006–2011. The scientific forecast is annually varied and used as a basis for Emercom annual forecast of emergencies in Russia. The annual report of the Emercom All-Russian Centre for Monitoring and Forecast of Emergency Situations issued in the beginning of 2009 (http://www.mchs.gov.ru/) states that in 2009 an emergency situation caused by a possible earthquake with M ≥ 7 could occur in the Southern part of the Kamchatka Peninsula, in the area of Kuril and Komandor Islands, in cities Petropavlovsk-Kamchatsky, Elizovo and Vilyuchinsk. The Kamchatka area is exposed as well as to natural and technological hazards. Thirty-five hazardous explosives and 22 hazardous chemical facilities are in operation now in the area. The population of the area is 478.8 thousands. Ninety percent of the Kamchatka region population lives in three cities: Petropavlovsk-Kamchatsky, Elizovo and Ust-Kamchatsk.

In order to develop implement preventive measures plans aimed at risk reduction in the area, estimations of possible consequences of expected events were made regularly for the whole area and for Petropavlovsk-Kamchatsky city during the past 10 years taking into account secondary natural and technological hazards (Larionov et al 1999a,b, 2000a,b 2000c, 2008). The Institute of Physics of the Earth, the Russian Academy of Sciences (RAS) and Institute of Volcanology, RAS identified six possible earthquake source zones. The parameters of the scenario events

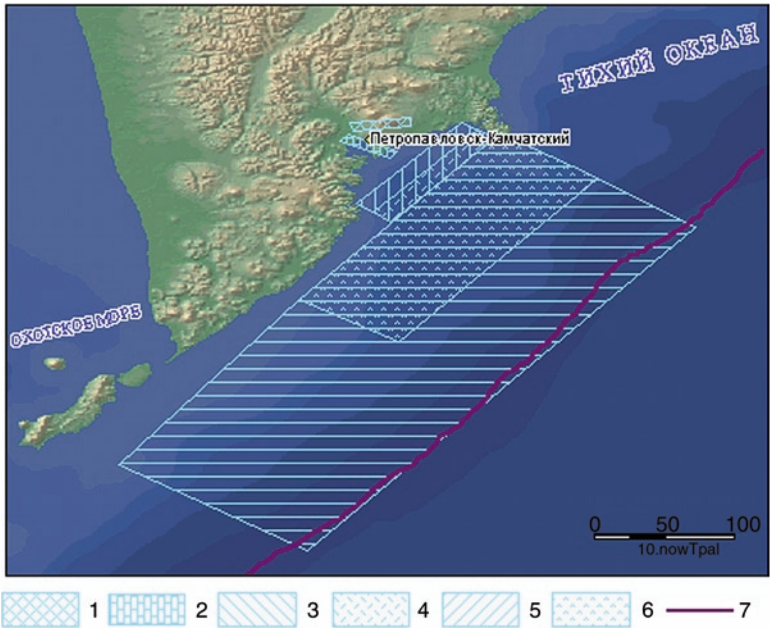

Fig. 10.1 Location of scenario earthquakes' zones: 1-VUL, 2-PET, 3-AVG, 4-AVS, 5-FZ9, 6-FZ8, 7-axis of the Pacific Ocean deep-water trough

Table 10.6 Scenario events parameters for Petropavlovsk-Kamchatsky city (Sobolev et al.1999)

Zone	Magnitude			Depth of seismoactive layer, km
Index	M_W/M_{LH}		Possible source zones	
FZ9	9.0	8.5	Pacific Ocean focal zone (earthquakes in subduction zone)	0–50
FZ8	8.4	8.25		0–50
AVS	7.8	7.9		0–50
AVG	7.8	7.9		60–150
PET	6.8	7.0	Shore zone of crust earthquakes (events of tectonic origin)	0–30
VUL	6.8	7.0	Shore zone of crust earthquakes (events of volcanic origin)	0–30

for Petrovavlovsk-Kamchatsky city are given in Table 10.6, their location is shown in Fig. 10.1.

The results of expected loss estimations for Petropavlovsk-Kamchatsky city with the "Extremum" system version application are shown in Table 10.7 and in Figs. 10.2–10.4

Figures 10.2 and 10.3 show that in the case of scenario earthquake in zone AVS the existing building stock will survive damage from light up to moderate; in the case of scenario event in zone PET partial and total collapse of buildings could prevail.

Table 10.7 Expected social losses and individual risk for the Petropavlovsk – Kamchatsky city due to scenario events (Table 10.6)

Zone index	Coordinates and source depth, km	Magnitude, reoccurrence, years	Seismic individual risk, 10^{-5}	Expected losses	
				Fatalities, persons	Injuries, persons
PET	158.600 E 53.000 N; 10	6.8–7.0; 3,000–30,000	1.0–8.0	7,260–15,460	16,180–33,120
VUL	158.800 E 53.200 N; 10	6.8–7.0; 2,000–20,000	1.0–10.0	5,590–12,860	12,580–32,310
FZ9	159.000 E 51.000 N; 26	9.0–8.5; 100–500	8.0–50.0	44–290	250–1,320
FZ8	159.400 E 52.100 N; 36	8.4–8.25; 50–500	10.0–45.0	220–810	720–3,270
AVS	159.300 E 52.700 N; 26	7.8–7.9; 30–100	30.0–300.0	850–2,610	2,450–8,150
AVG	159.200 E 52.800 N; 77	7.8–7.9; 300–3,000	4.0–15.0	570–1,760	1,650–6,330

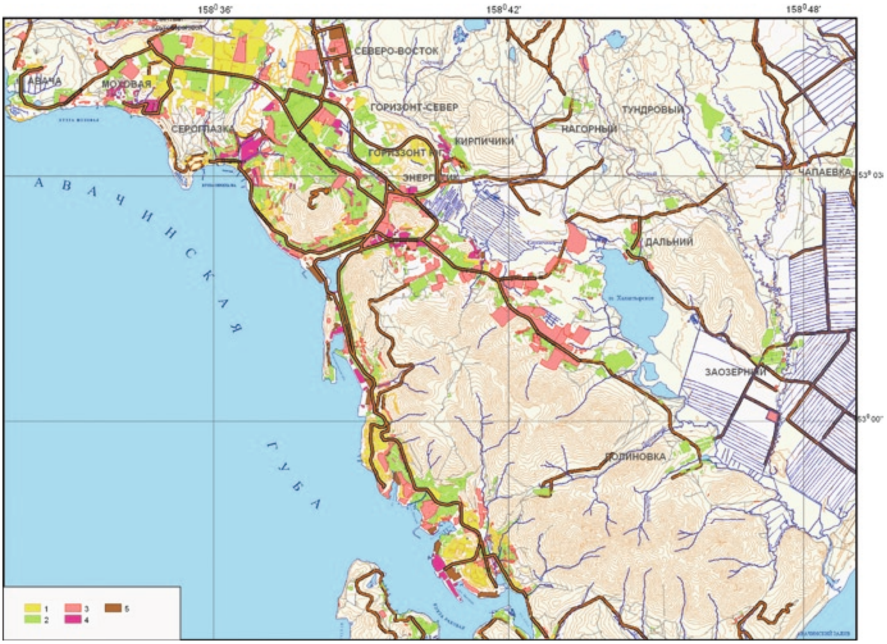

Fig. 10.2 Distribution of damage states due to scenario event in zone AVS

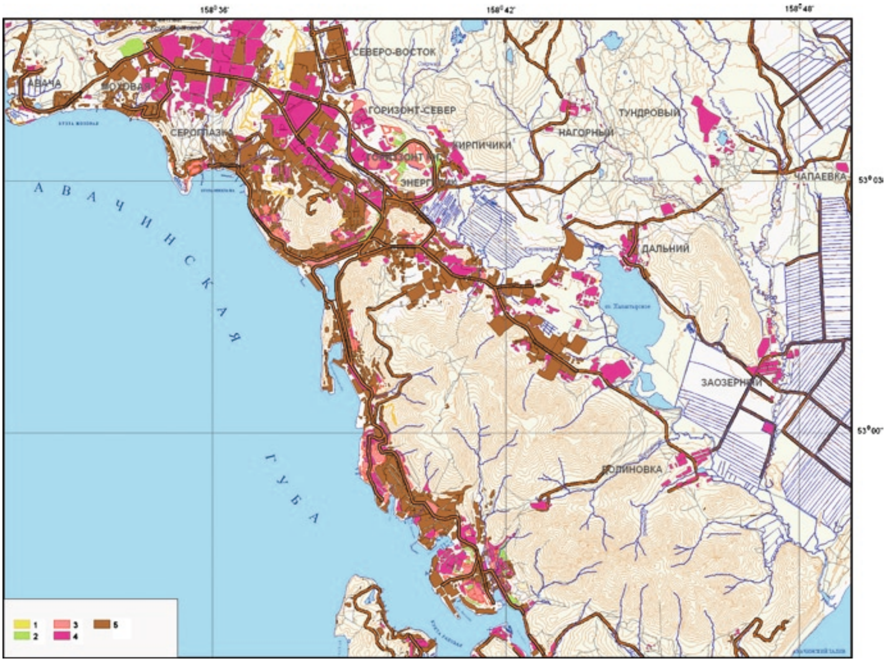

Fig. 10.3 Distribution of damage states due to scenario event in zone PET 1- light damage; 2-moderate damage; 3-heavy damage; 4-partial collapse; 5-total collapse

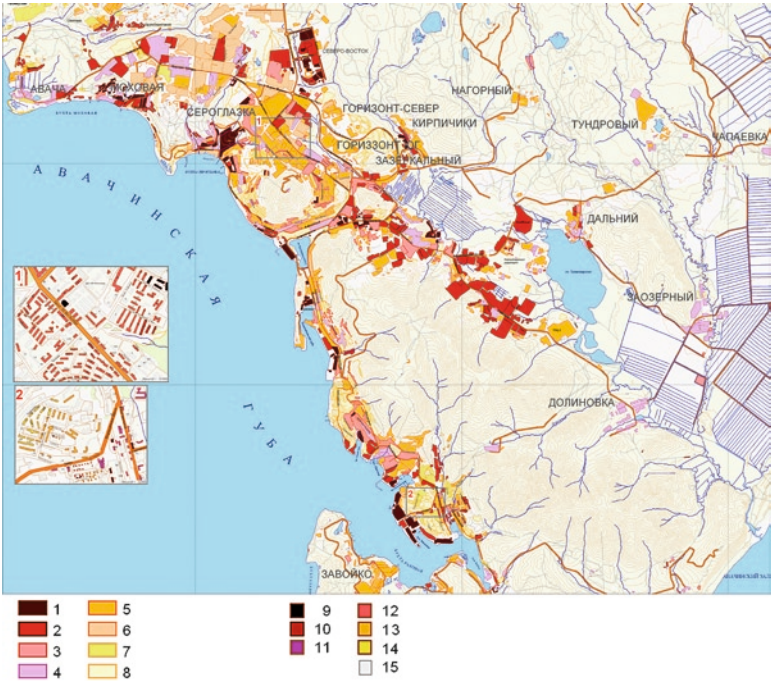

Fig. 10.4 Individual seismic risk zonation for Petropavlovsk-Kamchatsky city for the scenario event in zone AVS. Values of risk for city districts: 1– more than 2×10^{-3}; 2– 5×10^{-4}–2×10^{-3}; 3– 2×10^{-4}–5×10^{-4}; 4– 1×10^{-4}–2×10^{-4}; 5 – 5×10^{-5}–1×10^{-4}; 6 – 1×10^{-5}–5×10^{-5}; 7 – 5×10^{-6}–1×10^{-5}; 8 – less than 5×10^{-6}. Values of risk for buildings: 9 – more than 5×10^{-4}; 10 – 1×10^{-4}–5×10^{-4}; 11 – 5×10^{-5}–1×10^{-4}; 12 – 1×10^{-5}–5×10^{-5}; 13 – 5×10^{-6}–1×10^{-5}; 14 – less than 5×10^{-6}; 15 – no computations have been done

The analysis of Table 10.7 shows that the individual seismic risk range for different scenario event zones varies widely, from 1×10^{-5} up to 3×10^{-3}. The highest values of risk for population are obtained for the event in the zone AVS (Fig. 10.4). On average it is equal to 1.65×10^{-3}. Such values are considered to be high and require urgent measures for risk reduction.

Taking into account the fact that maximum values of earthquake risk are accounted for in zone AVS and maximum expected losses are characterised for scenario event in zone PET, which is characterised by low risk values, it was concluded that programmes, plans and preventive measures aimed at risk reduction should be developed and implemented in two stages. For long term planning the maximum expected losses should be taken into account: expected fatalities – 15,000 persons; injuries – 33,000 persons. In short term planning the measures should be implemented which take into account expected losses: fatalities – 2,600 persons; injuries – 8,000 persons.

Table 10.8 shows the number of inhabitants of Petropavlovsk-Kamchatsky city who live in zones with different individual seismic risk levels. About 30% of the

Table 10.8 Areas with different levels of individual seismic risk and number of inhabitants subjected to different levels of risk for the case of scenario earthquake in zone AVS

Risk ranges, R_s (1×10^{-5})	Area size		Number of inhabitants	
	m^2	%	Persons	%
Less than 0.5	3,034,105	11.6	21,285	10.2
0.5–1	1,250,095	4.8	9,590	4.6
1–5	6,708,897	25.7	64,697	31.1
5–10	3,662,154	14.0	29,203	14.1
10–20	3,156,303	12.1	23,855	11.5
20–50	2,312,517	8.8	16,587	8.0
50–200	4,735,090	18.1	33,777	16.3
More than 200	1,290,261	4.9	8,754	4.2

Table 10.9 Structure of casualties due to the scenario event in the Kamchatka area

Injury location	Total number of expected injured patients	Expected injured patients in each city		
		Petropavlovsk-Kamchatsky	Elizovo	Vilyuchinsk
Head	14,000	10,000	2,200	1,800
Thorax	6,350	4,500	1,000	850
Abdomen	770	550	120	100
Pelvis	3,500	2,500	550	450
Spine	2,800	2,000	450	350
Extremities	38,000	27,000	6,000	5,000
Multiple	7,700	5,500	1,200	1,000

city territory where about 50,000 inhabitants live is characterised by rather high and extremely high risk.

The other procedure described above and developed by the All-Russian Centre for Disaster Medicine “Zazhita” was used to develop the logistic planning for the whole Kamchatka area in the case of a scenario earthquake with $I = 8$. In the case of such an event Petropavlovsk-Kamchatsky, Elizovo and Vilyuchinsk cities will have the most number of medical casualties. For the whole Kamchatka area the number of severely injured may reach 7,500 persons and of moderate injured may be equal to 10,500 persons. An additional 10,000 inhabitants may have psychological illness and may be affected by hazardous materials released in the case of accidents at hazardous chemical, fire and explosive facilities triggered by a strong earthquake. In terms of types of injuries, about 50% of patients could have injuries to extremities and about 19%, head injuries. Crush-syndrome may be observed for about 1,800 inhabitants. About 700 patients may need haemodialysis. At present only 5% of haemodialysis could be provided by the medical facilities of the Kamchatka area. During the first 3 days these needs may be covered by the medical facilities of the Far East federal region. The breakdown of expected casualties in the case of scenario event with $I = 8$ is shown in Table 10.9.

Table 10.10 Dynamics of expected fatalities among the seriously injured people trapped under debris

Expected time of death after the moment of injury, h/days	Proportion of expected fatalities within the groups of patients with different levels of injuries: Seriously injured with life-threatening injuries	Seriously injured with injuries not threatening life	All seriously injured patients
>6 h	60	–	42
6–12 h	20	–	14
13–24 h	10	–	7
1–2 days	7	5	6
2–3 days	3	5	4
Total number within first 3 days	100	10	73
4–6 days	–	60	18
7–10 days	–	20	6
After 10 days	–	10	3

According to expert estimations more than 40% of severely injured people trapped under the debris may be dead within the first 6 h; in 12 h the number of expected fatalities is estimated as 56%. Dynamics of expected losses due to scenario event with $I = 8$ in the Kamchatka area for the first days is shown in Table 10.10.

The results of expected fatalities and injuries estimations due to scenario earthquake with $I = 8$ together with organizational issues dealing with medical support and affected population medical evacuation based on these loss estimations were used during the special training on March, 2009 in the Kamchatka area.

10.4 Conclusions

The completed study gave evidence that the main difficulties in scientifically based logistic planning in the case of emergency due to strong earthquakes are due to specific peculiarities of each event, as well as vulnerability of existing building stock and resources and manpower involved in medical response which result in different quantitative and qualitative characteristics of casualties. The creation of a unified classification of earthquake-related injuries and a medical registration system will contribute to collecting reliable information on injury structure and medico-evacuation patterns of the casualties.

Chapter 11
Seismic Vulnerability and Collapse Probability Assessment of Buildings in Greece

A. Pomonis, A. Kappos, F. Karababa, and G. Panagopoulos

Abstract The chapter focuses on the assessment of seismic vulnerability of buildings in Greece addressing all common typologies, with emphasis on collapse probability, which is directly related to the level of losses (casualties and economic losses). Two different approaches are presented for estimating the collapse probability of different types of buildings for the common values of the Modified Mercalli intensity (VI–IX), one based entirely on the processing of statistical data from past earthquakes in Greece, and one making use of hybrid (analytical and empirical) vulnerability curves; the percentage of population living or working in each building type is also estimated. Finally, some first comparisons with similar results from various other countries are presented. In addition a brief analysis of global earthquake fatality trends is presented which concludes that on a global level the risk to human life continues to be quite high.

11.1 Introduction

The primary incentive for the work described in this chapter came from the PAGER (Prompt Assessment of Global Earthquakes for Response) project carried out by the American U.S. Geological Survey in cooperation with WHE (World Housing Encyclopedia), a common action of EERI (Earthquake Engineering Research Institute) and IAEE (International Association for Earthquake Engineering). The aim of the

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project is to establish, with the aid of worldwide experts, an international database of seismic vulnerability for all building typologies commonly found in all countries, focusing on collapse probabilities at each level of macroseismic intensity, which is directly related to the level of losses (casualties and economic losses). The first two authors of this chapter were asked to contribute their expertise with regard to the Greek territory and thus contribute to the ambitious goals of this project. Two teams were subsequently formed (Risk Management Solutions, RMS and Aristotle University of Thessaloniki, AUTh) which, although they consulted independently using different methodologies and provided alternative approaches for the Greek building stock, maintained systematic communication and cooperation with each other.

This chapter presents the procedures followed to establish the building typologies found in Greece (to be used in the assessment of seismic vulnerability) and the estimation of collapse probabilities for each building typology and for each of the common values of MMI-EMS macroseismic intensity (VI–IX), as well as some first comparisons with similar results from various other countries.

11.2 Research Questions – Research Aims

The main aim of USGS/WHE with regard to the PAGER project was the development of a rapid post-seismic loss assessment (primarily in terms of human casualties). The relevant questionnaire which was developed and distributed for completion by worldwide experts included the following fields:

1. Type or material of construction. This requires selecting the most suitable entry from a table of potential categories based on construction materials and load bearing structural systems.
2. Description of the structural form.
3. Estimation of the collapse probability (%) for each building typology when subjected to a seismic action of a given intensity (the required intensity ranges between VI and IX).
4. The population percentage that resides in each building typology disaggregated into rural and urban areas.
5. The working population percentage that works in each building typology (for rural and urban areas).
6. The maximum average number of occupants for each building typology.

It should be emphasised that the procedure followed here for the purposes of PAGER differs significantly from a ‘typical’ seismic vulnerability assessment (e.g., through the use of damage probability matrices). A ‘typical’ assessment seeks to determine the degree of damage (in structural or economic terms) at each seismic intensity level. In many cases the degree of damage corresponding to partial or total collapse includes buildings which are demolished after an earthquake because their repair-retrofit is considered not feasible or uneconomic. Although in economic terms the outcome of this inclusion would be the same (cost of repair = cost of replacement), in terms of human losses (injuries/deaths) the difference would be very considerable.

The PAGER methodology therefore aims to rapidly estimate human casualties from earthquakes based on the fact that most earthquake fatalities around the globe are linked to the collapse of buildings (Allen et al. 2009a).

A study into the causes of death from earthquakes in the period 1900–1999 estimated that approximately 70–75% of lives were lost due to building collapse, while the remaining 25–30% were due to other causes such as tsunami, landslides and fire following the seismic event (Spence 2003). This continues to be the case to this day despite the 2004 Indian Ocean tsunami which killed 227,900 people. A similar conclusion was drawn by Marano et al. (2009) in their detailed analysis of global earthquake fatalities during the period September 1968 to June 2008. They established that in these 40 years, 77.7% of the deaths are related to ground shaking, 4.8% are related to landslides and 16.3% are related to tsunami.

The decade 2000–2009 was unfortunately one the worst since 1900, fatalities having reached 450,500. This clearly was because of the tremendous loss of life that occurred on 26 December, 2004 as a result of the Indian Ocean tsunami. Figure 11.1 shows that extreme variations exist in the temporal distribution of global earthquake deaths which is due to the spatial variation of earthquake activity related to the populated areas of the world but could also relate to variations in global earthquake energy released during the respective periods. The number of catalogued events in each decadal period is seen in the right-hand column of the chart.

When decadal global earthquake fatalities are normalised for global population the temporal variation diminishes but still the fatality rate (per 100,000 population) ranges from 23.8 in the period 1915–1924 to 0.58 in the 1950s (a factor of 41), with the decade 2000–2009 being the fifth worst (6.95 per 100,000 by 2009), as shown in Fig. 11.2.

We notice that the decadal fatality rate exceeded ten deaths per 100,000 people only in the 1920s, 1930s and 1970s. These high fatality rates are because of deaths in Chinese earthquakes (~235,000 in the 16 December, 1920 earthquake affecting Haiyuan and Guyuan counties and ~242,000 in the 28 July, 1976 Tangshan earthquake). For the 1976 Tangshan earthquake there is uncertainty about the actual

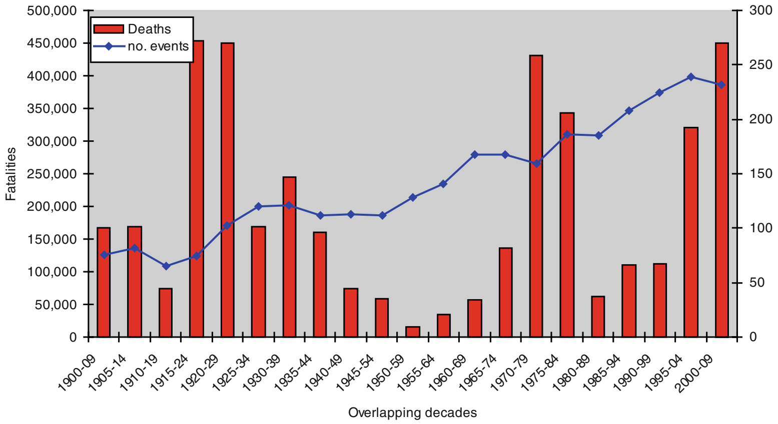

Fig. 11.1 Global earthquake fatalities by decade (1900-Sept. 30, 2009) and number of catalogued fatal events

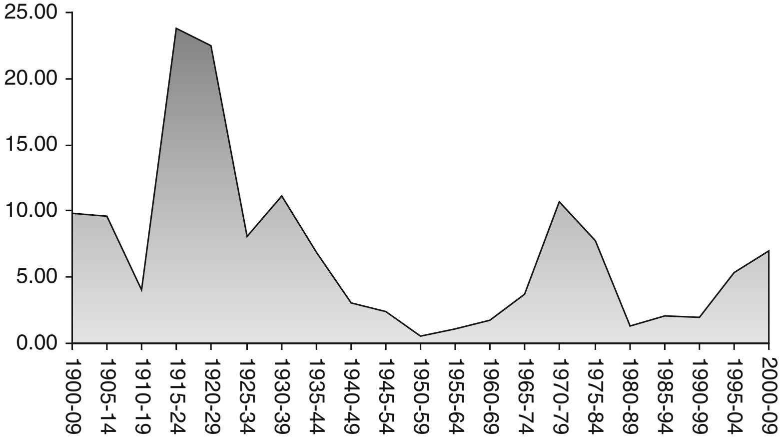

Fig. 11.2 Variation of global earthquake fatality rate 1900–2009 (lives lost per 100,000 population)

death toll, with the official figure being 242,419 but contemporary estimates from other Chinese entities (e.g. the Hebei Revolutionary Committee; the South China Morning Post in its 5 January, 1977, issue) gave 655,237 fatalities. In this analysis we have used the official figures although we believe that it is an underestimate.

It is clear that human vulnerability to earthquakes on a global scale continues to be considerable. Almost 89% of the global earthquake fatalities in the last 110 years have been caused by earthquakes of magnitude seven or greater. At a decadal level the average number of earthquakes with magnitude seven or greater in the period 1900–2005 is 194 (http://neic.usgs.gov/neis/eqlists/7up.html) but in some of the past 11 decades great earthquake activity was markedly lower, especially in the 1980s and 1990s when only 112 and 153 such events occurred (note that the pre-1990s magnitudes are being reviewed by the USGS with a plan to estimate the moment magnitude of all the great earthquakes so that better conclusions can be drawn). The low fatality rate of the 1980s and 1990s could also be related to this; on the other hand the 1920s high occurred in a decade that had fewer than average great events (171), while the 1950s minimum occurred during a decade with above average activity in terms of great events (209). Naturally the most important factor in the variation of the fatality rate is the frequency of great earthquakes near seismically vulnerable population concentrations.

In Greece, in the period 1900–2009 there have been approximately 1,500 deaths in 53 fatal earthquakes. In the last 40 years (1969–2008), 71.3% of the 271 earthquake-related fatalities have been associated with the collapse of about 35 reinforced concrete (RC) buildings and just 4.9% with the collapse of unreinforced masonry buildings (URM), while 23.8% are attributed to other causes such as falls, heart attacks and falling debris (no landslide or tsunami life losses occurred in these 40 years). RC buildings constitute the largest part of the Greek building stock with respect to built volume, as will be discussed below. Search and rescue (SAR) operations in Greece have in recent events saved a large number of trapped victims as shown in Table 11.1.

Table 11.1 History of SAR operations in Greek earthquakes

Earthquakes	Local time	SAR sites	Killed on site	Rescued	Event death toll	% deaths in SAR site(s)
Thessaloniki (June 20, 1978)	23:03	1	37	3	47	78.7
Corinth Gulf (February 24, 1981)	22:57	1	3	0	18	16.7
Kalamata (September 13, 1986)	20:24	1	6	13	20	30.0
Aigio (June 15, 1995)	03:15	2	26	68	26	100.0
Athens (September 7, 1999)	14:56	27	114	85	143	79.7
Total		32	186	169	254	73.2

11.3 Methodology of Seismic Vulnerability Assessment

In this section the methodologies used by the two groups (RMS and AUTh) as well as the data sources used will be described. The work took place over the October–November 2007 period on a tight time allowance. More research has since taken place to collate Greek earthquake damage survey data from earthquakes of the past 30 years in Greece which will be reported in a forthcoming paper.

11.3.1 Available Damage Databases

The availability of statistically processed damage data constitutes a fundamental component in seismic vulnerability assessments. The data that were available to and usable by both co-operating teams were obtained primarily from the following damage databases:

- 20 June, 1978 Thessaloniki earthquake: This constitutes currently the most complete damage database with regard to the Greek territory. It comprises 5,470 buildings (density of on-site recording 1:2 blocks) located within an area covering nearly half of the central part of the city, and contains detailed data regarding both the buildings' characteristics, as well as damage descriptions and repair costs (Penelis et al. 1986).
- 13 September, 1986 Kalamata earthquake: 7,101 buildings were analysed from a total of 10,171, classified in one of four categories (green, yellow, red and purple) according to the degree of damage they sustained. This is the only post-earthquake damage database in Greece which employed the additional 'purple' category, used to quantify the buildings which actually collapsed or were so severely damaged that they were considered not repairable (OASP 1986–1989; Lekidis et al. 1987; Andrikopoulou 1989).
- 15 June, 1995 Aigio earthquake: The database was compiled from the research team of the University of Patras (Fardis et al. 1999) and includes the entire

building stock of the Aigio city centre, among which the majority of the damaged buildings from RC and unreinforced load bearing masonry (URM) are found. The database consists of 2,014 buildings, of which 857 (42.5%) are URM.
- 7 September, 1999 Athens (Mount Parnitha) earthquake: The database was compiled within the framework of a previous research project involving teams from AUTh and ITSAK (Kappos et al. 2007). The collected damage data constitute a representative sample from the region of Ano Liosia (150 building blocks, approximately 10% of the total number of building blocks of the Municipality).
- Damage database from ‘Ethniki’ Insurance (Ethniki Asfalistiki): This database was compiled as part of the ARISTION research project and comprises 2,149 entries (entire buildings or parts of buildings, e.g., individual apartments or shops), 96.9% of which are related to the 1999 Mount Parnitha earthquake and 3.1% to the 2003 Lefkada Island earthquake (YPEHODE-OASP 2005).

11.3.2 Definition of Building Typologies

Within the framework of the current research, it was observed that the Greek building stock (mainly concrete, masonry, timber and metal frame) is adequately described by utilising six out of the 33 building typologies suggested by PAGER. However, for RC buildings which constitute the dominant building typology in Greece, it was considered necessary to introduce an additional division of the stock into sub-classes (not necessarily identical for both research teams) based on characteristics which have been shown to influence the seismic vulnerability of structures such as age, height and lateral resistance to seismic actions. In the end, the two teams used slightly different building typologies which are described below in more detail.

11.3.3 RMS Methodology

The methodology followed by RMS was based entirely on empirical damage data from the earthquakes of Kalamata in 1986, Aigio in 1995 and Athens in 1999.

The destructive earthquake of 13 September, 1986 (M_W 6.0) that occurred at 20:24 local time in the southern part of the Peloponnese, severely affected the city of Kalamata. Its epicentre was located 9 km north of the city. The main event was followed by a number of aftershocks, the strongest of which occurred 2 days later with a magnitude M5.3 about 1 km east of the city. The main shock resulted in the loss of 20 lives, heavy building damage as well as the collapse of a 22-unit five-storeyed RC apartment block. Several more buildings collapsed during the main aftershock (Anagnostopoulos et al. 1987).

The damage survey data from Kalamata are disaggregated by structural type into RC, URM and mixed load-bearing system buildings (usually older masonry buildings with more recent RC extensions either horizontally or vertically or both), as well as by the number of floors (1–7 floors). The data cover 26 neighbourhoods of the city and concerned 7,101 buildings (the total building stock in the city of Kalamata was 10,171 and has been entirely surveyed, but the data at neighbourhood level was analysed before the completion of the entire usability survey which took more than 2 months to complete). The neighbourhood level sub-set allows the assessment of damage in a range of seismic intensities because damage varied substantially within the city due to soil conditions, source and directivity effects due to the causative fault's proximity to the city (Gariel et al. 1991). We have checked the damage distribution by structural type and height of the buildings when using the 7,101 buildings neighbourhood-level sub-set instead of the city level total of 10,171 buildings and have found the distributions to be very similar. Figure 11.3 shows the damage distribution of buildings per damage state and by structural load-bearing system (buildings of mixed load-bearing systems have been grouped together with those of URM) and the number of floors.

In order to estimate the required collapse probabilities of the various buildings by the structural load-bearing typology, in areas with seismic intensities ranging from VI to IX, it was first necessary to assess the intensities experienced in the various neighbourhoods of the city. This was achieved through reference to the URM data, because historically intensity scales were developed with exclusive reference to this building typology. The assessed seismic intensities per neighbourhood are presented in Table 11.2. It should be noted that the damage data combine the resulting actions of both the main earthquake as well as of the aftershocks. The average seismic intensity for the 19 neighbourhoods was assessed as 9.17 based on the percentage of URM buildings in each neighbourhood with regard to the total. This value is in agreement with the assessment by Papazachos and Papazachou (2002) who reported the intensity in the city of Kalamata as IX. The maximum recorded horizontal peak ground accelerations (PGA) were 0.30 and 0.27 g in the city centre and in the neighbourhood of Nisaki respectively (Anagnostopoulos et al. 1987). The duration of the strong seismic motion in the main event (acceleration >0.10 g) was 2.3 s.

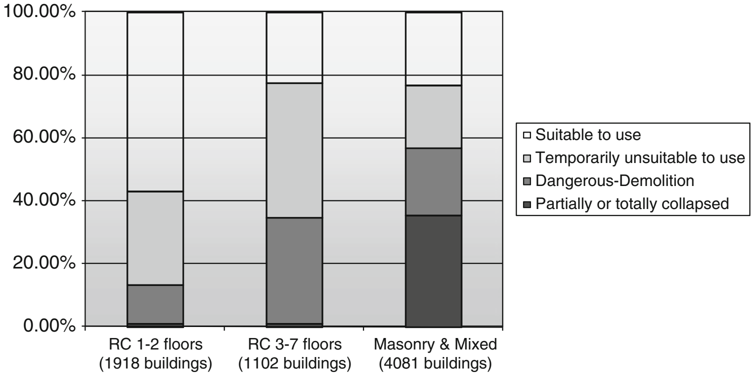

Fig. 11.3 Damage distribution in the city of Kalamata following the 1986 earthquake

Table 11.2 Estimated macroseismic intensities in 19 neighbourhoods of Kalamata during the 1986 earthquake

Neighbourhood	Intensity (EMS)	Number of buildings
Kordias	<VI	57
Dytiki Paralia, Anatoliki Paralia, Goulimides	VII–VIII	621
Paralia, Aghia Triada	VIII	734
Akrita	VIII–IX	97
Rachi, Athinon, Nisaki, Kolimvitirio, Giannitsanika	IX	2,181
Aghia Paraskevi, Aghios Georgios	IX–X	551
Papadakou, Bariamaga, Fytia, Palaia Poli, Kentro	X	2,713

Furthermore, the mean horizontal spectral accelerations for the period 0.1–0.3 s were 0.84 and 0.62 g respectively and the peak horizontal ground velocities (PGV) were 30–40 cm/s.

The number of surveyed RC buildings were 2,950 (1,863 had 1–2 floors and 1,087 had 3–7 floors). Although the data do not include the year of construction, it is known from the 1990 Buildings Census of Greece that in the city of Kalamata the majority (>80%) have been constructed between 1960 and 1983 complying with the 1959 Greek earthquake code. Twenty-six RC buildings were assigned the purple-tag which translates to a partial or complete collapse rate of 0.88% (18 had 1–2 floors and eight had 3–7 floors, with respective rates of 0.97% and 0.74%).

Buildings of URM and mixed load-bearing masonry were analysed both separately and jointly (there were 2,959 URM buildings and 1,045 buildings with a ‘mixed’ load-bearing system); in total, 1,420 buildings suffered severe damage often deemed to be beyond repair (1,231 URM and 189 mixed structure buildings with severe damage rates of 41.6% and 18.1% respectively). However the collapse definition for the purple URM buildings is not the same as the one proposed by PAGER whereby a building is considered to have collapsed when a 50% volume reduction or more has taken place at one or more floors. Typically in Greece URM buildings which are overwhelmingly of the rubble or hewn-stone variety (for more detailed descriptions of URM buildings in Southern Greece (see Karantoni and Bouckovalas 1997)) are considered uninhabitable and thus are destined for demolition even when no volume loss has taken place, e.g. a very common damage pattern is the out-of-plane failure of one wall although often the floor or roof above remain in place. Therefore the collapse probabilities for Greek URM buildings proposed here are not a good predictor of earthquake casualties. It has not been possible so far to estimate the proportion of URM buildings that have been red or purple tagged in Greece that actually have a volume loss less than 50% in any floor; this is therefore an item for future research. Further analyses were performed for various combinations of load-bearing masonry and neighbourhoods. In Fig. 11.4 the purple-tag percentages for URM, mixed load-bearing buildings are shown in relation to the assessed seismic intensity (some neighbourhoods were aggregated in order to increase the sample size and reduce uncertainty). In general, the purple-tag percentage increases smoothly as the assessed intensities increase, despite the fact that the analysis is based on empirical data and some discontinuities are expected due to the

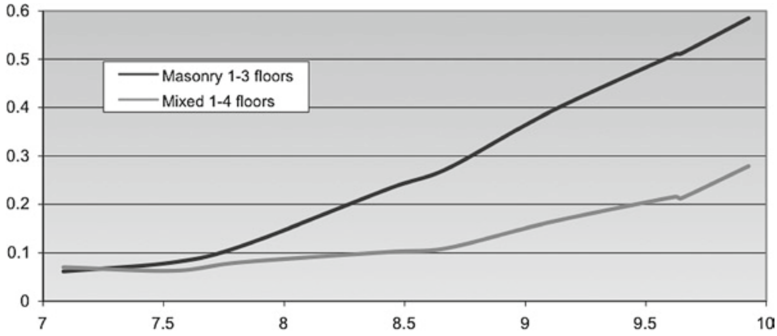

Fig. 11.4 Estimation of collapse probability for URM and mixed URM+RC buildings with respect to the level of seismic intensity using the neighbourhood level data from the 1986 Kalamata earthquake

uncertainty in the accurate assessment of the damageability of the seismic action in the various neighbourhoods of Kalamata.

For the RC buildings there is also reference in the study by Andrikopoulou (1989) which contains the final damage distribution for all the buildings in Kalamata (10,171 buildings) but not at neighbourhood level, whereby it is reported that the purple-tag percentage of low-rise RC buildings was 1.14% (34 collapses in 2,975 buildings) while for the mid-rise (3–7 floors) 0.81% (ten collapses in 1,229 buildings) i.e., a little higher than the data used in the current analysis. Although there were 44 RC and 2,220 URM and mixed structure purple-tag buildings there were only 20 lives lost. Six deaths were caused by the collapse of a five-storey RC building (the percentage of fatal (deadly) collapses being 0.024% in the total number of RC buildings or 0.081% in the sub-category of high-rise RC buildings), four were caused by the collapse of URM buildings (unspecified number), six were caused on the streets by falling plaster and walls (mainly due to the collapse of URM) and four from other causes (Anagnostopoulos et al. 1987). However, loss of life may have been greater had the earthquake occurred a few hours later.

On 15 June, 1995 at 03:16 local time an earthquake of $M_s = 6.2$ occurred 15 km to the east of Aigio city in northern Peloponnese. The damage in the city of Aigio was severe. The data from the 1995 Aigio earthquake refer to 2,106 buildings in the city centre (1,157 RC and 859 URM buildings) out of the 7,200 that existed in the city and its surrounding suburbs at the time of the earthquake (Fardis et al. 1999). Among the major findings of this survey was the better performance of RC buildings constructed after 1984 as well as the uneven spatial distribution of damage with the areas to the north of the Aigio fault (i.e. the coastal zone of the city) exhibiting much less damage in comparison to the city centre. Seismic intensity in the city of Aigio ranged between VII and VIII+. The peak horizontal ground accelerations (PGA) recorded were 0.54 and 0.49 g in the city centre (Telecommunications building), while the peak vertical acceleration was 0.20 g (Athanasopoulos et al. 1998). The duration of the strong seismic motion (acceleration >0.10 g) was 2.5 s. The mean horizontal spectral acceleration for the period range between 0.1 and 0.5 s was very high and reached a value of 0.95 g and the horizontal ground velocity (PGV) recorded was 48 cm/s.

Building collapses occurred in Aigio and 26 lives were lost in two multi-storey RC building collapses (Theofili and Vetere Arellano 2001) one being a seven-storey residential apartment block and the other a five-storey hotel. The number of RC buildings in the city was approximately 4,300 (percentage of fatal collapse 0.047%). One more RC building collapsed just outside the city boundary (the administrative centre in a factory complex housing an operation of the Greek Arms Industry) but was thankfully vacant at the time of the earthquake.

As previously mentioned, in the Mount Parnitha 1999 earthquake there were 120 recorded lives lost connected with the collapse of 26 RC buildings (Pomonis 2002). In the six municipalities where the collapses occurred there were 37,062 RC buildings (Building Census ESYE-December 2000) i.e. the lethal collapse percentage was 0.070%. Seismic intensity in the six municipalities ranged between VI and VIII–IX. The highest intensities were observed in small districts where the collapse percentage was higher, for example the area near the Chelidonou stream. No strong motion instrument existed in the worst-affected areas at the time of the earthquake.

The proposed collapse probabilities are presented in Table 11.3.

The suggested probabilities for low-rise (1–2 storeys) masonry buildings (URM buildings from stone or solid-brick masonry, typically without mortar and with timber floors as well as URM buildings from cement-block or brick masonry with mortar and RC floors) are in agreement with the findings presented in Fig. 11.3. For RC buildings collapse probabilities are provided for three construction periods (prior to 1961, 1961–1995 and after 1995) for low-rise (1–2 floors) and multi-storey buildings (3–7 floors) separately. The suggested probabilities are generally in good agreement with the Kalamata and Aigio observations for buildings constructed prior to 1995.

For the purposes of the PAGER project a building is considered to have collapsed when it sustains 50% or more loss of volume in at least one of its storeys. The observations from Kalamata, Aigio and Mount Parnitha earthquakes showed that many buildings which were considered collapsed had a much smaller loss of volume (especially in the case of URM buildings), a fact supported by the limited loss of life which occurred in very few buildings and the limited number of fatalities linked to the collapse of URM buildings. The final proposed collapse probabilities were thus reduced in order to take this into account.

11.3.4 Aristotle University of Thessaloniki Methodology

Statistical damage data from Greek earthquakes are available, in general, in terms of the classifications used in the first-round (rapid) post-seismic damage inspections – green, yellow, red – and in financial terms (cost of replacement) only for the 1978 Thessaloniki earthquake (Penelis et al. 1986) and the 1999 Athens earthquake (Ethniki Asfalistiki database). Data regarding the buildings that actually collapsed were available only in the Kalamata database. The Aristotle University of Thessaloniki (AUTh) team has developed over the last years a complete set of vulnerability

Table 11.3 Collapse probabilities and population percentages (RMS methodology)

Material or construction type (according to WHE)	Description of construction type	Probability of collapse (%) of building type when subjected to specified shaking intensity (MMI-EMS-MSK)				Percentage (%) of population living in this building type	
		IX	VIII	VII	VI	Urban areas	Rural areas
16 (a)	RC MRF with clay brick masonry infill. Post-1995; 3–7 floors	N/A	N/A	0.00	0.00	10.8	6.1
16 (b)	As 16(a). 1961–95 (low code); 3–7 floors	0.35	0.20	0.00	0.00	62.2	18.9
14 (a)	As 16(a). Pre-1961 (no code); 3–7 floors	0.70	0.45	0.17	0.00	7.9	2.0
16 (c)	As 16(a). Post- 1995 (high code); 1–2 floors	N/A	N/A	0.00	0.00	2.1	7.1
16 (d)	As 16(a). Built in 1961–95 (low code); 1–2 floors	0.40	0.25	0.00	0.00	12.0	22.1
14 (b)	As 16(a). Pre-1961 (no code); 1–2 floors	1.15	0.75	0.25	0.00	1.5	2.3
1	Rubble stone masonry usually on lime mortar with wooden floors. Built before 1961. 1–2 floors	40.00	21.00	7.00	0.00	1.1	20.6
9	Unreinforced brick masonry usually with cement mortar and RC floors. Mostly pre-1960. Usually 1–2 floors	16.00	7.00	2.50	0.00	2.3	20.6

curves for all the common building typologies, mainly reinforced concrete (54 classes) and load-bearing masonry (four classes), found in Greece (Fig. 11.5). This has been achieved using a ‘hybrid’ approach which combines statistical damage data with the results from multiple inelastic analyses, both of static and dynamic (only for RC buildings) nature (Kappos et al. 2006; Kappos and Panagopoulos 2009).

It has been observed that most of the available data, although useful per se for the purposes of seismic vulnerability assessment, do not provide satisfactory results with regard to the assessment of collapse probabilities. This is because at the level of intensity where collapse occurs (mostly in the dominant RC class) statistical data, on the one hand, are insufficient, while analytical data on the other hand are in general unreliable (usually too conservative). Therefore, the research effort concentrated on the systematic reprocessing of the available statistical data placing the focus on the

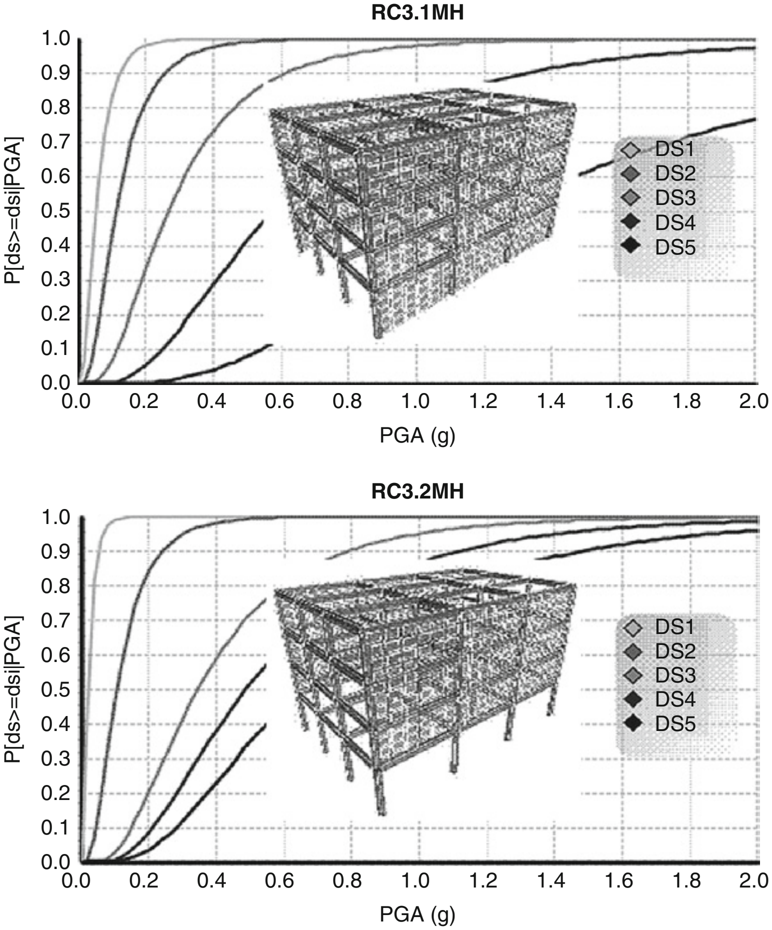

Fig. 11.5 Seismic vulnerability curves for medium-rise RC frame buildings with brick-infill (top) and with pilotis (bottom) designed according to the latest seismic codes (NEAK/EAK 2000)

differentiation between buildings that collapsed and those that required demolition after an earthquake (most valuable were the data concerning approximately 10,000 buildings which were damaged from the 1986 earthquake in Kalamata), as well as the use of the hybrid approach with the subsequently revised statistical data.

Only six out of the 58 building types used by the AUTh research team were considered suitable for this study and were further used in the estimation of collapse probabilities (Table 11.4). From the 54 RC building classes differentiating buildings by age, height, structural system and the existence or absence of masonry infill, only four were used, differentiating buildings on the basis of their structural system (frame or dual) and their age (buildings designed with the old or new seismic codes). RC buildings which were designed with the ‘Additional Clauses’ of the 1985 code were considered to exhibit similar behaviour with regard to vulnerability with those designed with the new code (NEAK/EAK 2000). Similarly, only two classes were considered for load-bearing masonry buildings differentiating them on the basis of their construction materials (stone or brick masonry) with no further differentiation by height, as was the case in the evaluation of the associated vulnerability curves (Kappos et al. 2006). The aggregation of the various building typologies is due to the fact that the available statistical data and especially those referring to actual building collapses are limited, and further distinctions would require arbitrary assumptions which could in turn lead to unreliable conclusions. For metal frame and timber buildings the AUTh team did not have sufficient statistical or analytical data to evaluate their seismic vulnerability and therefore it was decided to refrain from estimating their corresponding collapse probabilities.

The procedure followed for the estimation of collapse probabilities for every building typology and for the intensity range between VI and IX comprises two stages. First, the probability that the buildings have sustained damage levels ranging from ‘heavy damage’ to ‘collapse’ is estimated in one of the following ways:

- From the number of buildings classified as ‘red’ in the available damage databases, in the case where sufficient data exist for the concerned building typology.
- From the available vulnerability curves (Kappos et al. 2006; Kappos and Panagopoulos 2009) the probability that the peak ground acceleration (PGA) corresponding to every intensity level has exceeded the value of PGA corresponding to damage level 4, (representing the degree of ‘heavy damage’ (P[ds>ds4|PGA]) is evaluated assuming that damage state 4 and 5 represent the state of buildings when classified as red. For the application of the hybrid approach the intensities for which statistical data are available are converted to PGA using the most recent among the empirical equations for Greece (Koliopoulos et al. 1998). Vulnerability curves have been developed for 54 RC and four URM building typologies and therefore for this study average curves are evaluated from the relevant typologies that can be aggregated into more generic classes (e.g., RC frame buildings designed to old seismic codes).

The next stage involves the evaluation of the number of buildings which actually collapsed (purple), using mainly the available data from the Kalamata database, in terms of the sum of the buildings which sustained damage ranging from ‘heavy’ to ‘collapsed’ for each one of the studied building typologies.

Table 11.4 Collapse probabilities and population percentages (AUTh methodology)

Material or construction type (according to WHE)	Description of construction type	Probability of collapse (%) of building type when subjected to specified shaking intensity				Percentage (%) of population living in this building type	
		IX	VIII	VII	VI	Urban areas	Rural areas
16	RC MRF building designed with old codes	1.00	0.35	0.10	0.05	50.0	25.0
16	RC MRF building designed with new codes	0.40	0.10	0.05	0.00	7.5	9.0
19	RC dual system building designed with old codes	0.75	0.25	0.10	0.01	12.5	3.0
19	RC dual system building designed with new codes	0.35	0.05	0.01	0.00	22.0	9.0
1	Stone masonry buildings	55.00	10.00	5.00	3.00	1.5	23.0
9	Unreinforced brick masonry buildings	7.50	1.00	0.10	0.00	5.5	30.0

11.4 Estimation of the Population Living or Working in Each Building Typology

The percentage of the population living or working in each building typology was determined through systematic processing of the building and population census data provided by ESYE (National Statistical Service of Greece) in 2001 as well as their projections to 2007 (these data are fundamental for determining loss of life). The ESYE data are provided separately for both urban and rural areas allowing, thus, the separate estimation of the above for each regional type and in turn the detection of any significant differences.

The AUTh team followed similar assumptions for the population distributions, but for the distribution of buildings according to their ability to resist seismic actions it was assumed that in urban areas 80% of the buildings designed before 1985 have a frame structure and 20% a dual system, while for buildings constructed after 1985 the corresponding percentages are 35% and 65% respectively. For rural areas it was assumed that 90% of the buildings designed before 1985 have a frame structure and 10% a dual system, while for buildings constructed after 1985 the corresponding percentages are 60% and 40% respectively. Furthermore, additional assumptions were made based on the data available through the Thessaloniki and Athens databases (Ano Liosia and Ethniki Asfalistiki database) in terms of the average floor area for each building typology (buildings of dual system are typically larger than frame buildings). The results of the analysis are presented in Table 11.4. The fields for which the team did not have the necessary data required for the estimation of the corresponding values were left blank (following the instructions by the PAGER team). These fields are however covered by the RMS submission.

11.5 Results-Comparisons with Other Countries

The results of the analyses performed by the two teams, as discussed above, are presented in Table 11.3 (RMS) and Table 11.4 (AUTh). The level of agreement in the results provided by the two teams is satisfactory, which was somewhat expected given that the primary data used by both teams were identical (available damage databases), although the methodologies were fundamentally different.

The results from various other countries are already available through PAGER and it is therefore of great interest to compare them with the Greek results. Figures 11.6 and 11.7 compare the probabilities of collapse for stone masonry and RC buildings respectively, with the results from 14 countries which in their majority are characterised as zones of high seismic risk, although there are countries (such as Germany, France and Switzerland) of low to medium seismic risk.

A large spread is observed in the submitted results regarding the probability of collapse (but also among the building typologies present in each country which are not shown in the figures). This is somewhat expected given differences in the

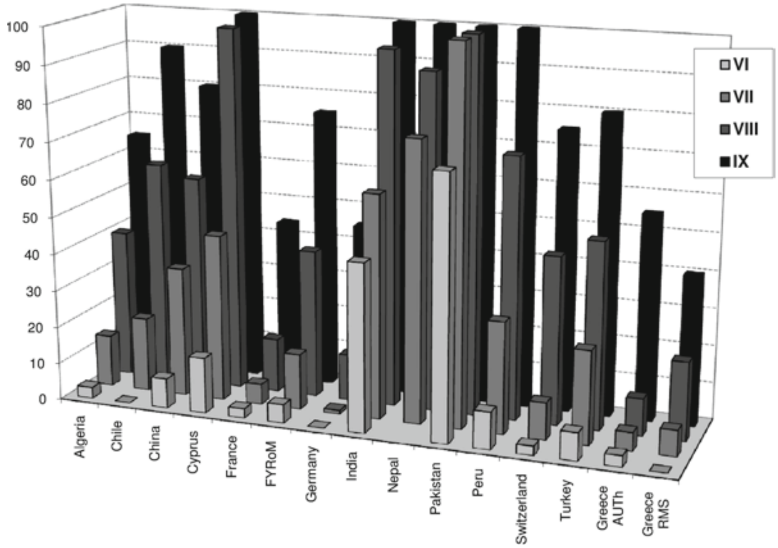

Fig. 11.6 Collapse probabilities in the intensity range VI to IX for unreinforced stone masonry buildings as requested by EERI and provided by experts in various countries.

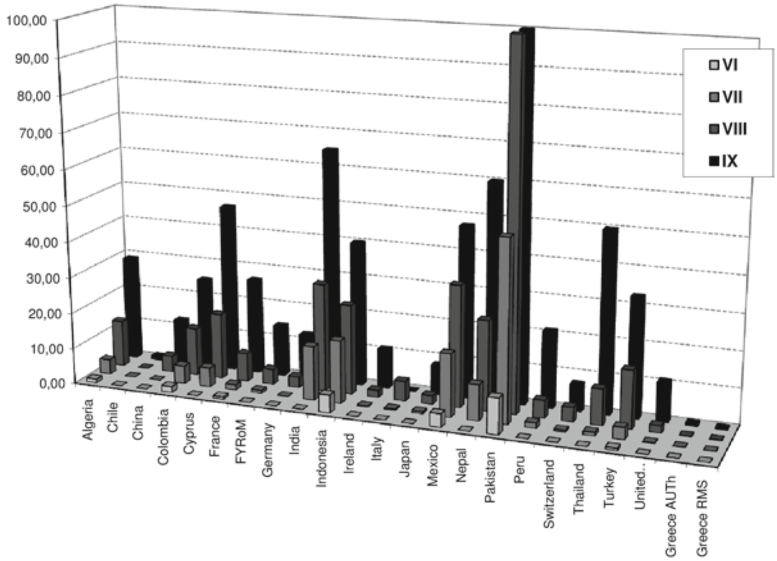

Fig. 11.7 Collapse probabilities in the intensity range VI to IX for reinforced concrete buildings as requested by EERI and provided by experts in various countries.

Table 11.5 Correspondence of Intensity (I) and peak ground acceleration (PGA) with various assumptions

I	PGA (Koliopoulos et al. 1998)	PGA (WHE PAGER form)
VI	0.089 g	~0.092–0.18 g
VII	0.187 g	~0.18–0.34 g
VIII	0.391 g	~0.34–0.65 g
IX	0.820 g	~0.65–1.24 g

construction types found in each country as well as differences in their economic and social status (for example the probabilities of collapse of stone masonry buildings are far greater in countries such as India, Pakistan and Peru in comparison to countries such as France, Germany and Greece as shown in Fig. 11.6). However, to a large extent the observed spread (especially for RC buildings, shown in Fig. 11.7) is the effect of the different methodologies adopted for the estimation of collapse probabilities by experts in each country, since no specific guidelines were provided with regard to the procedure to be followed in estimating such probabilities. It is obvious to the authors of this paper that the particularly high collapse probabilities suggested by some country experts have not been estimated following the strict assumption regarding collapse as previously mentioned, but include buildings which have sustained heavy damage and may have been demolished at a later stage. An additional reason for the observed spread is the classification of buildings into typologies which may vary from country to country. For example, as shown in Fig. 11.7, the probabilities of collapse for buildings with RC shear walls in Chile are zero for all intensities apart from IX (where collapse probabilities are 1%) which are known to behave better than frame structures (for which no probabilities are provided).

Finally, it should be noted that an additional factor leading to the observed differences among international findings is the correspondence between intensity and acceleration (e.g., in the hybrid methodology of AUTh the analyses are performed for successively increasing values of acceleration in the records used). Table 11.5 shows the values of the peak ground acceleration (PGA) as computed from the relationship proposed by Koliopoulos et al. (1998) and used in the analyses of AUTh as well as the range of values adopted in the PAGER project (based primarily on American experience). The largest differences are observed in the lower intensities for which the Greek values lie far from the mean (or in cases outside) of the range of values of the PAGER project.

11.6 Conclusions

Estimations of building collapse probabilities due to earthquakes (which are directly related to loss of life as well as economic losses) for all common building typologies found in Greece were presented in this paper (for the first time), together with estimations of the population percentage that lives or works in each building typology (of fundamental importance in the determination of loss of life).

Two methodologies were used for the estimation of collapse probabilities for each building typology for the most common macroseismic intensities (VI–IX); one based exclusively on the statistical processing of damage data from Greek earthquakes and one utilising hybrid (analytical and empirical) vulnerability curves developed by the AUTh research team. The results were compared to those from various other countries, both of high and low seismic risk, geographically covering four continents.

As expected, it was confirmed that the available statistical data, although valuable, do not allow for the differentiation of many building typologies while the values of the collapse probabilities do not always exhibit the expected change with respect to seismic intensity. Furthermore, collapse probabilities are sensitive to the assumptions made for statistically processing damage data and for the utilisation of vulnerability curves. The difficulty in estimating collapse probabilities is that estimations are based on a very small number of collapsed buildings, which differs significantly from the (usually available) number of buildings exhibiting heavy damage (red tag) and which may be demolished after an earthquake. The insufficiency of statistical data, in addition to the uncertainty in the distinction between buildings which actually collapsed to those which were heavily damaged are among the main reasons that explain the considerable differences observed when comparing the results of this study with those from a total of 14 countries. Furthermore, the differences in building quality among the various countries should not be overlooked.

The current study constitutes an initial attempt at estimating building collapse probabilities based on expert opinion and was completed within a limited time frame that did not allow for more detailed analyses. Further in-depth analyses regarding the various assumptions made, e.g., the choice of seismic intensity in earthquake struck areas, the correspondence of seismic intensities with acceleration and velocity parameters (ground and spectral) as well as with other parameters used to describe strong motion ‘damageability’ will provide greater reliability and accuracy to the estimations and will facilitate the development of scenarios to be used for improved preparedness and mitigation actions against seismic risk in Greece.

Acknowledgments The authors would like to express their gratitude to the Earthquake Planning and Protection Organisation of Greece (OASP) and the Institute of Engineering and Earthquake Resistant Construction in Thessaloniki (ITSAK) for kindly providing seismic vulnerability data for buildings in Greece as well as to EERI and USGS who are responsible for the PAGER project.

Chapter 12
Seismic Casualty Evaluation: The Italian Model, an Application to the L'Aquila 2009 Event

G. Zuccaro and F. Cacace

Abstract In this chapter a possible model for evaluating seismic casualties in Italy is presented. The factors influencing the evaluation are discussed and the results of the first investigations concerning their quantification are presented. The model is directly derived from the original idea of Coburn and Spence (1992); the adaptation of the model to the Italian context has been possible thanks to the data collected in the field regarding either the percentage of the victims per structural type or the lifestyle of the population obtained from the National Institute of Statistics (ISTAT). This has enabled the estimation of some of the most important parameters: the time and duration of the indoor occupancy of the population in the day, in the week, in the year. Other factors, such as the increment of population due to seasonal tourist flows or the increase of low energy seismic activity before the damaging event are discussed. Finally an application of the model to the earthquake of L'Aquila which occurred on 6 April 2009 is presented. The comparison of the official data of the human and structural damage with the simulation results show very good agreement. Considering the considerable uncertainty of the separate factors influencing the final evaluation of the casualty model, this result has to be taken with great caution and considered a favourable case rather than proof of the reliability of the model; however it represents an encouraging step toward the definition of a reliable casualty model while acknowledging that further investigation and calibration are required.

12.1 Introduction

The evaluation of human casualties due to seismic events represents surely one of the most complex problems in seismic impact assessment; the number of deaths and injured can vary significantly between different earthquakes of similar characteristics.

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This is because many factors can affect the number of casualties during an earthquake; in this chapter some investigations to parameterise these factors are presented.

Assuming as a first approximation that the percentage of seismic casualties is directly proportional the population density in the affected area (exposure), the problem can be first approached as follows:

$$K_i = \frac{N_i}{N_T} \quad K_d = \frac{N_d}{N_T} \tag{12.1}$$

Where:

K_i = ratio of injured

K_d = ratio of deaths

N_T = number of people in the area

N_i = number of injured

N_d = number of deaths

We assume the injured are people with severe physical injuries requiring hospital treatment.

The sum of $K_i + K_d$ represents the total physical damage to the population; the ratio K_i/K_d, is not always constant. It has been observed (Wyss et al. 2009a, b) that generally it varies according to quality of construction of the city, and that this ratio has significantly increased in the last 50 years. This is especially true in the industrialised countries, where now it is, on average, 2–3 times greater than in the developing countries.

The possible factors influencing the casualties occurring after an earthquake are many; a list of these aspects follows.

12.2 Vulnerability Factors Influencing the Number of Casualties

12.2.1 Structural and Non-Structural Damage

International statistics show that seismic casualties are mainly caused by structural failure. Seventy-five percent of the total human losses are in fact attributed to structural causes, especially for strong earthquakes where victims due to building collapse predominate. The losses deriving from non-structural causes are relatively low. They are dominant for low levels of ground shaking; they are very variable and difficult to foresee. The losses deriving from secondary effects (landslide, fire, etc.), infrastructure failures (viaducts, bridges, etc.) or simply panic, are factors that only rarely constitute a significant proportion of the total losses. Considering that for a moderate level of seismic intensity (V–VII) the non-structural damage is generally directly proportional to the structural damage;

it can be assumed that the number of injured and deaths is strictly correlated to the structural damage itself. Therefore the probability of injury or death of the building occupants can be evaluated as a function of the damage level of the building. In particular it can be assumed that K_{i} and K_d are significant only for damage levels D4 and D5.

12.2.2 Vertical Building Structural Typology

The experience of past seismic events has shown that for equal structural damage levels the probability of injury or death is significantly influenced by the structural typology. The rate of mortality is higher for framed structures (especially for R.C. structures) than for masonry structures, while the probability of injury for framed structures is slightly higher but still comparable to that for masonry buildings.

In the present paper the casualty evaluation is obtained as a proportion of the occupants of the building, according to damage level, classified by vertical building structure type: Reinforced Concrete or Masonry (see Table 12.1). These factors are calibrated on the basis of previous earthquake surveys; further development of the research will pursue the definition of the casualty as percentage of the occupancy of the EMS ’98 vulnerability classes (A, B, C, D) (Grünthal 1998). The “C” class includes masonry and R.C. buildings because strong masonry and weak R.C. may manifest analogue seismic response.

12.2.3 Geometrical Characteristics

It has been observed that buildings having the same volume show significant variations in the rate of injury or deaths, which are strongly dependent on the number of storeys. Therefore the casualty rates are higher in the case of tower blocks than for buildings having a large footprint and few storeys.

Table 12.1 Casualty percentage by damage level and building type

	Damage level							
Casualty percentage	D0	D1	D2	D3	D4	D5	Vertical structure	Vulnerability class
QD	0	0	0	0	0.04	0.15	Masonry	A or B or C
QD	0	0	0	0	0.08	0.3	R.C.	C or D
QI	0	0	0	0	0.14	0.7	Masonry	A or B or C
QI	0	0	0	0	0.12	0.5	R.C.	C or D

12.2.4 Distribution of the Population in Different Building Typologies

The density of the people in the building (K_b) can be evaluated by the following ratio:

$$K_b = \frac{N_b}{V} \tag{12.2}$$

where:

N_b = number of persons in the building; V= building volume.

This ratio is not dependant on the density of the population in the area considered.

The number of the occupants of the building is dependent on the volume, the typology and the age of the building. In general, if the total population and the building typologies of the studied area are known, it is possible to estimate with a reasonable approximation the distribution of the population associated with the vulnerability classes. Hence, available information on the volumes of the buildings in the area may considerably increase the reliability of the casualty estimation. It has to be taken into account that this kind of estimation is calibrated using residential buildings, therefore the ratio K_b can vary strongly for buildings having different use classes, such as industries, schools, offices, churches, shopping centres, etc.

12.3 Exposure Factors Influencing the Number of Casualties

As has been said above, seismic casualties are dependent on the overall population density in the area affected by the earthquake. However, this is not sufficient to determine the actual population exposed. In fact it has to be considered that only a small percentage of the inhabitants remain constantly in their home, while most people move daily for work or study, for social or entertainment activities, as well as for religious and other reasons.

Population mobility, i.e. from the satellite towns towards the larger urban settlements can significantly modify the exposure. Moreover, as previously observed, the increase of non-residential buildings have brought about modification to the population density for building types. Therefore any loss evaluation is strongly dependent on the instant at which the event occurs. Thus the population affected depends on the month (long period), on the day of the week and on the hour (short term) of the event. In this regard the collapse of the Balvano Church, during the 1980 event in Irpinia, can be mentioned. It occurred on a Sunday during Mass and caused 80 deaths; or the collapse of San Giuliano di Puglia school during the earthquake in Molise of 2002 which occurred during school hours, as a result of which

27 children died. In the case of the recent earthquake of L'Aquila, the model based on residential occupancy, gives a good approximation to reality since the seismic event occurred during the night, when residential occupancy is at its maximum level and easier to predict.

12.3.1 Variation of Exposure over the Day (Short Term) and over the Week (Mid-Term)

In order to evaluate the variation of the exposure during the day, the time and the duration of the population's daily trips have to be evaluated. There is not much information available in this regard; however it is sufficient to make a first approximate analysis.

An important source of useful information is the investigation on "times of everyday life" carried out by the National Institute of Statistics (ISTAT 2007); another similar analysis has been carried out by the (Municipality of Torino 2003) relating to Torino town and its satellite towns.

From the data collected at national level the timetable of the occupancy during working days and holidays can be derived (Fig. 12.1).

While analysing the data of the Municipality of Torino the timetable of residential occupancy for Monday-Friday, Saturday, and Sunday is derived (Figs. 12.2 through 12.4).

Therefore using these data, and assuming they apply to Italy as a whole is possible to determine the hours in which the population is mainly at home or in other indoor places.

Working on the data of the "Piano Territoriale di Coordinamento" (Provincia di Torino 2003) of the Provinces, it is also possible to derive useful information on the daily population trips from the satellite towns to the main town and to assume percentages of the exchange population flows as an approximate base for evaluations of the total population in the town. In the following table the origin-destination matrix of the Torino Province is shown (Table 12.2).

12.3.2 Variation of the Exposure in a Year (Long Term)

The variation in occupancy over a year is generally seasonal and mainly relates, in Italy, to tourist flows. Therefore casualty estimations involving touristic villages and towns require specific analyses of the information of the touristic presence through the year. The following tables show the variation of the "touristic" index, definable as the ratio of the touristic arrivals divided by resident population, in European countries and in the main Italian art cities; and the variation in the touristic index through the year (Figs. 12.5 and 12.6).

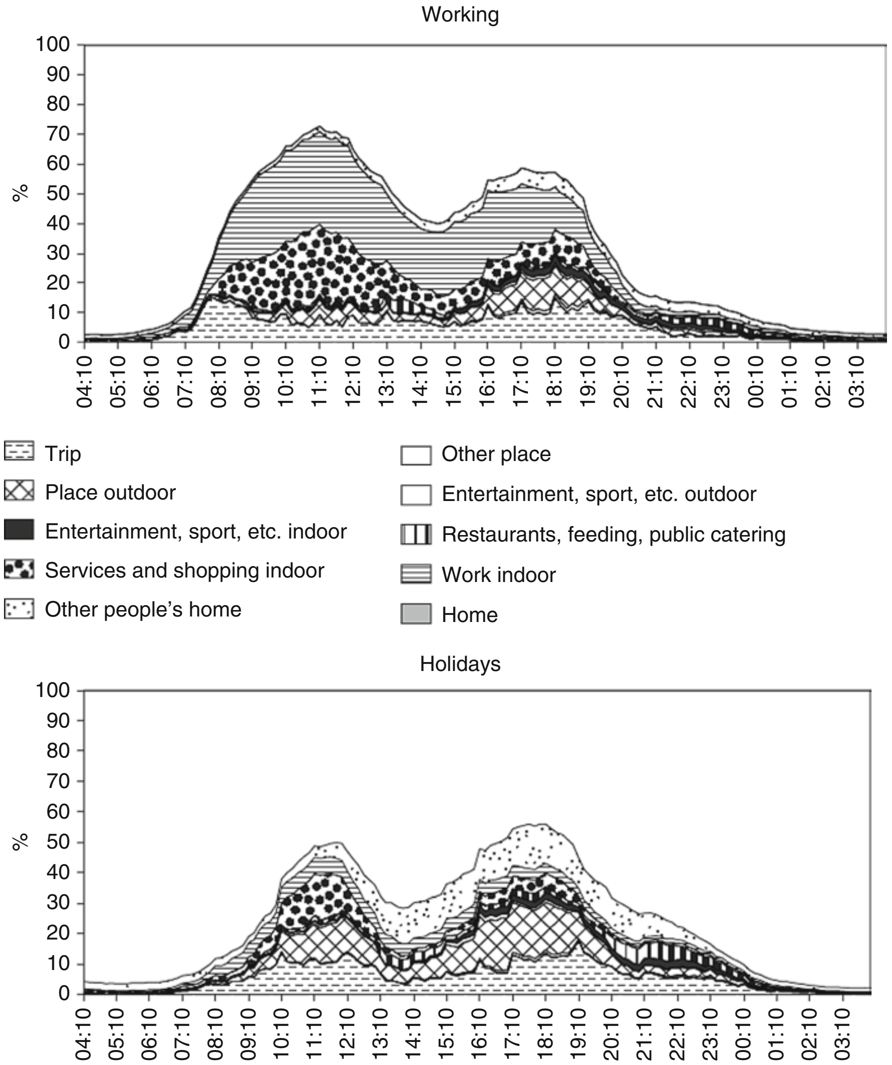

Fig. 12.1 Occupancy distribution during working days and holidays (Belloni 2006)

12.3.3 Variation in Exposure due to Low Seismic Activity Before the Damaging Event

The evaluation of occupancy may vary consistently either because of a sequence of damaging events (Irpinia '80) or because of the activation of a seismic crisis at low energy release that influences some people to leave the area (Umbria '97). This problem is now under close examination by a group of international experts and is

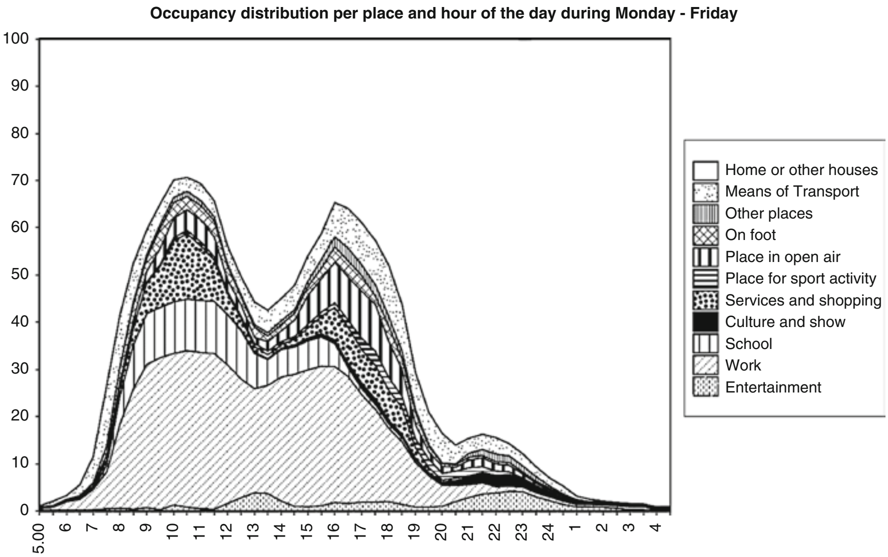

Fig. 12.2 Occupancy distribution during the working days of the week

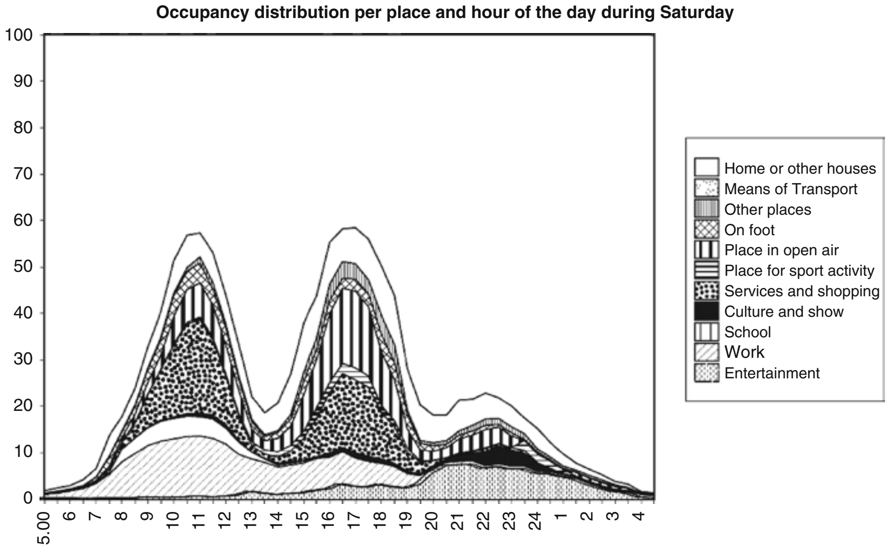

Fig. 12.3 Occupancy distribution on Saturday

the responsibility of the Italian Civil Protection as far as the management of the L'Aquila event is concerned. To manage this delicate aspect of the emergency a protocol of actions to follow is urgently required; it has to be agreed between the authority and the scientific community.

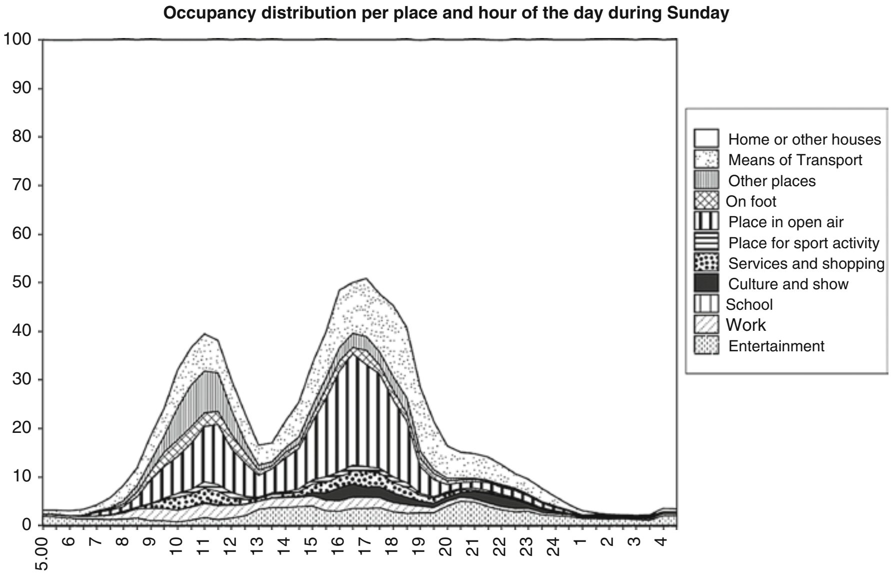

Fig. 12.4 Occupancy distribution on Sunday

Table 12.2 Daily origin-destination matrix of the Torino Province, total no. of trips

		Origin					
		Ivrea	Lanzo	Susa	Pinerolo	Torino	Total
Destination	Ivrea	77,714	507	136	187	5,964	6,794
	Lanzo	343	13,333	52	55	2,937	3,387
	Susa	70	20	16,887	116	1,782	1,988
	Pinerolo	135	42	77	47,362	4,958	5,212
	Torino	11,471	9,800	6,041	12,930	953,856	40,242
	Total	12,019	10,369	6,306	13,288	15,641	57,623

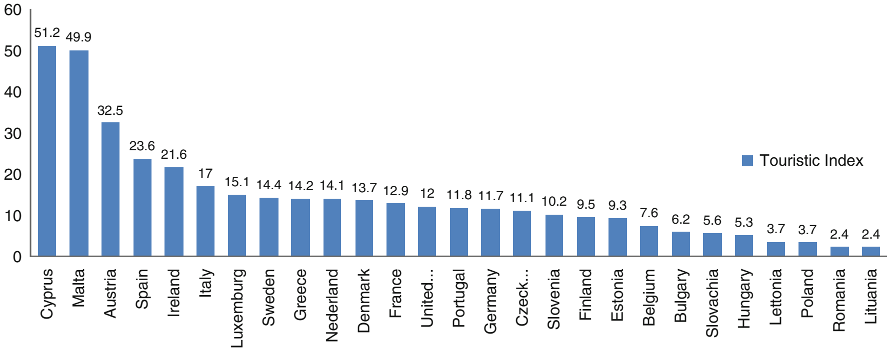

Fig. 12.5 Touristic index in Europe (as a percentage of total population

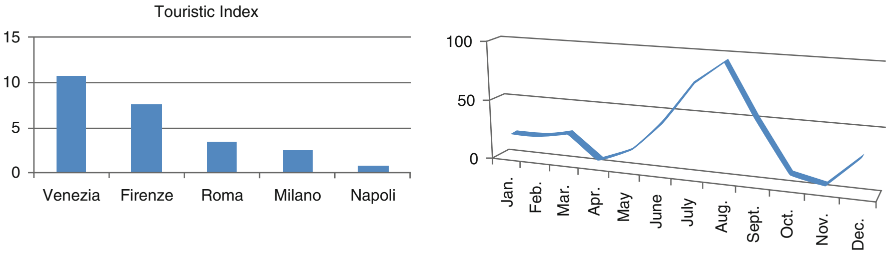

Fig. 12.6 Touristic index in the art cities in Italy and its variation through the year (percentage of total population)

12.4 Basic Elements of the Casualty Model

The seismic casualty model assumed is derived from an original idea developed in 1992 (Coburn and Spence 1992) and it is based on the evaluation of four fundamental parameters in addition to the total population on the site:

- Mean of inhabitants by building type (vulnerability class)
- Occupancy rate by hour of the day and week
- Touristic index by town and period of the year
- Casualty percentage by building type and damage level

The number of deaths (N_d) and injured (N_i) are then determined by the algorithms:

$$N_d = TI_c \cdot \sum_{t=1}^{4} \sum_{j=1}^{5} N_{t,j} NO_t \; QD_{t,j} \tag{12.3}$$

$$N_i = TI_c \cdot \sum_{t=1}^{4} \sum_{j=1}^{5} N_{t,j} NO_t \; QI_{t,j} \tag{12.4}$$

where:

t = building type ($t = 1, \ldots 4$)
j = damage level ($j = 1, \ldots\ldots 5$)
$N_{t,j}$ = number of buildings of type t having damage level j
NO_t = number of occupants (at the time of the event) by building type
TI_c = Touristic Index by city
$QD_{t,j}$ = proportion of deaths by building type and damage level
$QI_{t,j}$ = proportion of injured by building type and damage level

A further result of the casualty model is the evaluation of numbers left homeless. The number of the homeless could be assessed as the number of the residents in the unsafe buildings minus the number of the estimated deaths:

Table 12.3 Unsafe building percentages per damage level

Damage level d_j	0	1	2	3	4	5
Percentage of unsafe buildings I_j	2%	5%	10%	50%	100%	100%

$$NH = \sum_{t=1}^{4} \left[\sum_{j=0}^{5} N_{t,j} I_j \;\; Nr_t \right] - Nr_{dt} \tag{12.5}$$

$N_{t,j}$: number of buildings of type *t* having damage level *j* (*j*= 0, 1, 2,… 5)I_j : proportion of unsafe buildings (see Table 12.3)Nr_t : number of resident people by building typeNr_{dt}: N_d/TI_c number of estimated resident deaths by building type

An analysis of the database relevant to the private building estate inspected after different earthquakes has shown that the probability of having unsafe buildings does not strongly depend on the building typology but rather on the level of structural damage (DPC 2002).

A possible distribution of unsafe buildings according to the damage levels has been calibrated using the data of a wide sample of buildings surveyed after past events and is presented in Table 12.3.

12.5 Application

The model has been applied to the recent seismic event which occurred on 6 April, 2009 at L'Aquila in Italy. The Study Centre PLINIVS of the University of Naples, a Centre of Competence of the National Department of Civil Protection (DPC), just few hours after the event (when the dimension of the damage and the number of the victims was not yet clear) published an impact scenario on the web of the DPC with an estimation of the damage to the buildings and casualties.

The structural typologies of the area affected by the event were available in the database inventory at PLINIVS Centre. The inventory of the building stock at national scale has been derived by ISTAT Census 2001 statistically corrected at PLINIVS Centre using a sample of 254 city surveys in relevant Municipalities selected on the basis of population class and other specific characteristics (Zuccaro and Cacace 2009). The building typologies have been assumed as in the EMS 98 scale corrected as in the SAVE project (Zuccaro 2005; Zuccaro and Cacace 2006, 2009) (See Fig. 12.7).

The evaluation of the building damage distribution has been assessed using the Damage Probability Matrices (DPM) developed in previous research at PLINIVS Centre by fitting the damage observed in past events to the building typology of the inventory with a binomial distribution.

In Table 12.4 the binomial coefficients applied are shown. The separate DPMs for each building type (vulnerability classes) can be easily derived applying the formula:

$$V_{khi} = \frac{5!}{k!(5-k)!} \cdot p_{hi}^{k} (1 - p_{hi})^{5-k} \tag{12.6}$$

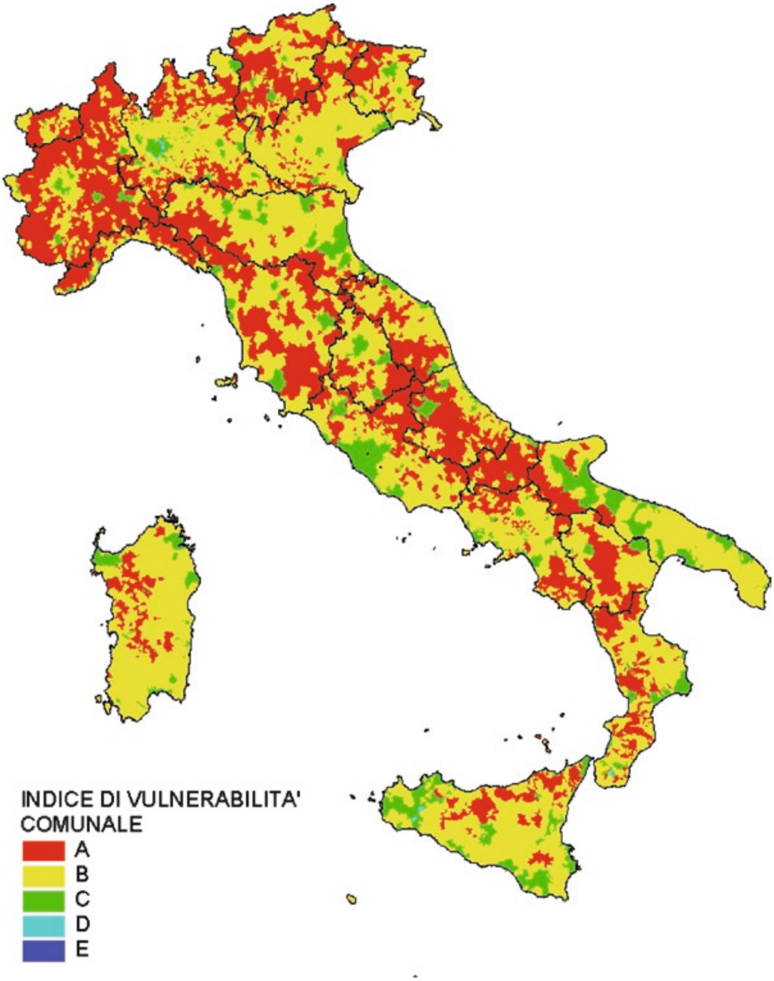

Fig. 12.7 Vulnerability class distribution at national scale

where:

k = damage level (k = 1, … 5)
h = building typology (h = A, B, …… F)
i = seismic intensity

The values in the light shaded cells represent the results of recent refinements (Zuccaro and Cacace 2009), those in the darker shading are theoretical values not used in this chapter. The building typology considered in the simulation are A, B, C and D only; this has been decided because building types E and F are poorly represented in the area. The results of the simulation are reported in the following tables and maps (Figs. 12.8 and 12.9).

Table 12.4 Binomial coefficients of the DPM (Zuccaro and Cacace 2009)

	V	VI	VII	VIII	IX	X	XI
A	0.19	0.22	0.28	0.42	0.6	0.72	0.82
B	0.12	0.15	0.19	0.26	0.36	0.5	0.7
C	0.08	0.1	0.12	0.16	0.21	0.26	0.48
D	0.03	0.05	0.08	0.11	0.15	0.22	0.46
E	0.01	0.03	0.05	0.08	0.12	0.17	0.4
F	0	0.01	0.03	0.05	0.09	0.15	0.35

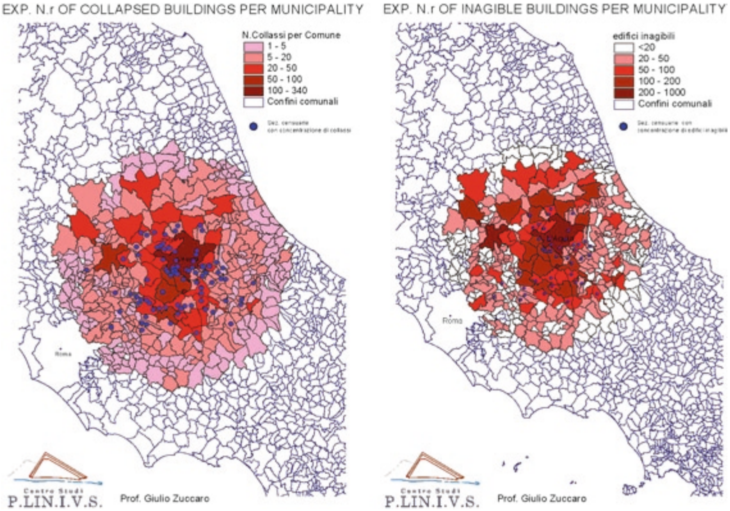

Fig. 12.8 Scenarios of building damage and unsafe buildings

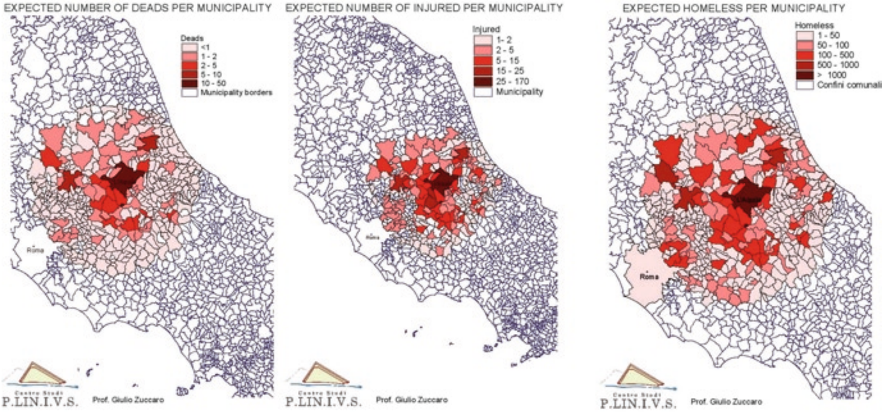

Fig. 12.9 Scenarios of casualties

Table 12.5 Official data on building damage (updated to 7 June 2009)

No. of buildings	48,790	1,083	53	162	575	1,271
	Private	Public	Hospital	Barracks	School	Productive activities
A	53.8%	55.3%	43.4%	69.1%	49.6%	60.3%
B	13.2%	16.6%	34.0%	23.5%	29.4%	16.8%
C	2.7%	3.9%	11.3%	3.1%	2.3%	3.9%
D	0.9%	1.5%	1.9%	0.0%	2.6%	0.7%
E	24.5%	19.7%	9.4%	4.3%	14.6%	14.5%
F	4.8%	3.0%	0.0%	0.0%	1.6%	3.8%

The rows from A to F are the safety check outcomes and specifically: A: % safe buildings; B: % buildings safe with emergency assistance; C: % partially unsafe buildings ; D: % temporarily unsafe buildings to be surveyed again; E: % unsafe buildings; F: % unsafe buildings posing an external indirect risk.

Table 12.6 Comparison of the results of the simulation with the results of the survey

	Simulation	Survey
Buidlings failed	259	Not consolidated
Buidlings damaged	84,000	Not consolidated
Buidlings unfit for use	13,080	12,500
Deaths	263	260 + 34
Injured	977	1,456
Homeless	58,500	45,000–70,000

The official data on buildings damage released by the DPC one month after the disaster for the 52,161 buildings surveyed were as shown in Table 12.5.

The sum of the outcomes C and E gives the number of the buildings unfit for use which equates to 12,500 buildings.

Comparing the results of the simulation with the results of the survey (Table 12.6) a surprising agreement is found.

In Table 12.6 the number of deaths are split into deaths at the time of the earthquake (260) and people who died in the 2 months after the event (34) as a result of medical complications.

12.6 Conclusions

In this chapter, a model to evaluate seismic casualties has been presented, and discussion of the factors influencing the algorithm has shown the great uncertainty of the numerous variables. These variables have been investigated through the analysis of original data collected by the Italian National Institute of Statistics and by other authorities. The study has quantified the range of variability of the factors influencing the results and a first attempt to improve the original model developed in 1992 by Coburn and Spence is presented.

In this chapter the first approximate quantification of these factors is shown. The application of the model to the L'Aquila earthquake has produced an unexpected agreement both with the actual reported casualties and with the information available on building damage. Awareness of the complexity and of the uncertainty of the separate parameters contributing to the final scenario suggests that the results should be viewed with great caution, conscious of the wide margin of potential improvement in the model. However the application reported encourages the development of other analyses and further calibration of the parameters of the model in order to achieve the most reliable result.

Chapter 13
Mortality and Morbidity Risk in the L'Aquila, Italy Earthquake of 6 April 2009 and Lessons to be Learned

D.E. Alexander

Abstract In the earthquake of 6 April 2009 at L'Aquila, Abruzzo Region, Italy, 308 people died and more than 1,500 were injured. The event and its consequences for injury epidemiology are analysed here. Anomalous patterns of mortality included an excessively high death toll in the 20–29 age group and among women aged 30–39. Mortality is compared with the demographics of L'Aquila and Abruzzo Region. In relation to aggregate patterns of social activity the paper then explores what patterns of injury might have developed if the earthquake had occurred at a different time of day. Secondly, as mortality was nocturnal and thus largely limited to vernacular housing, profiles are developed of characteristic patterns of building collapse leading to injury with respect to a prototype unreinforced masonry building and an apartment building in reinforced concrete which together characterise vernacular housing in the area. Initial findings suggest that social class was an important determinant of mortality among residents (although perhaps not among students and other temporary residents). Knowledge of building failure modes can offer some ideas about how improved self-protective behaviour could help reduce the likelihood of death or injury. This chapter considers the obstacles to developing personal protection and offers a scale that relates damage to injury potential. With reference to the building failure modes encountered at L'Aquila, it proposes a basic strategy for minimising risk of injury during earthquakes. To be truly learned, lessons must be incorporated into disaster risk reduction. In seismic zones, this must involve developing a culture of earthquake readiness among ordinary people.

13.1 Introduction

At 03.32 h on Monday 6 April 2009 an earthquake of magnitudes M_L 5.8 and M_W 6.3 occurred with epicentre a few kilometres southwest of the city of L'Aquila (population 72,800), capital of Abruzzo Region in central Italy. The tremors killed

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308 people and injured at least 1,500,202 of them seriously or critically. Mean peak acceleration on hard rock was 0.3 g, but on soft sediments it reached values of 0.7–1.0 g. Destruction was substantial in L'Aquila city and its 14 satellite villages, as well as in 15 other municipalities. In the end, 96 local authorities reported damage and in 49 of them it was significant enough to attract central government help. This was the worst earthquake disaster in Italy for 29 years. With a duration of 25–30 s, the main shock was the most powerful among a series of tremors that began in October 2008 and formed an earthquake swarm of a kind that is not uncommon in the central Apennines. Seismic damage occurred further south in Abruzzo region in 1984 (Alexander 1986), but the earthquake of 1915 at Avezzano killed 32,000 people, including 97% of the population of that city (Beal 1915). Another powerful earthquake is expected in the region within a decade (Peace et al. 2006).

With reference to the L'Aquila earthquake, this paper will examine the pattern of mortality and the characteristics of building failure. It will develop a pair of simple, standardised models of the latter and consider the risks associated with being caught in a building that undergoes partial or total collapse. Eventually, it may be possible to develop strategies to promote self-protective behaviour and thus reduce the toll of casualties. To do this it will be necessary to develop a popular culture of *earthquake readiness*.

13.2 Pattern of Fatalities Caused by the Earthquake

The L'Aquila earthquake occurred when most people were sleeping. Analyses of world-wide patterns of casualties suggest that between 50% and 90% of deaths in earthquakes occur between midnight and 6 a.m. (as seismic casualty data are notoriously irregular, the difference depends on the period covered by the records; Alexander 1996; Jones et al. 1990). Studies in central America and Turkey highlight the importance of vernacular housing as a source of risk in nocturnal earthquakes, or, indeed, whenever people are likely to be at home (Glass et al. 1977; Angus 1997; Rodriguez 2005). That is equally true in Italy (De Bruycker et al. 1983, 1985), where the only buildings that are more vulnerable to collapse (and may on occasion be fully occupied) are ecclesiastical ones. Some of these are very large, extremely old, poorly maintained and not seismically retrofitted (Lagomarsino and Podestà 2004).

The economic viability of human settlements in Abruzzo Region is significantly related to their demographic growth or decline. Generally, the smaller, more rural or isolated settlements lose population to the larger ones where economic opportunity is greater. In the region, a total of 81 municipalities were affected by the earthquake and 49 of them were inserted into the Prime Ministerial Decree regarding damage at EMS intensities VI–IX (DPCM 2009; Grünthal 1998). Although there is considerable statistical variation (relating mainly to employment opportunities near L'Aquila city, close to the Adriatic Sea coast and around trunk roads), the break-even point that divides decline from growth, measured on the basis of changes over the period 2001–2007, is a population of about 1,500 (Fig. 13.1), which is the same as it was at the time of the last significant earthquake in the region (Alexander

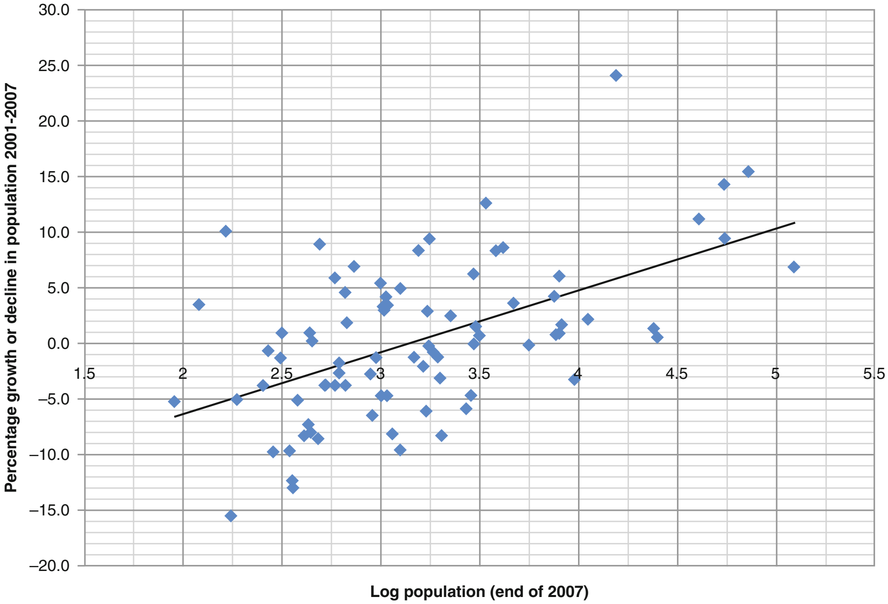

Fig. 13.1 Population growth or decline, 2001–2007, for 81 municipalities in Abruzzo Region affected by the 6 April 2009 L'Aquila earthquake

1986). It is interesting to note that the eight municipalities in which fatalities occurred are all growing, on average by a healthy 3.7% per decade. Even if deaths can be connected with building collapse in areas of poor quality housing, demographic stagnation is certainly not a factor.

The distribution of the 308 deaths involves a relatively circumscribed area 24 × 11 km in size (Fig. 13.2). The density of population plays some role, as does the geotechnical and geomorphological setting, especially regarding soft sediments and piedmont location. Hence Onna, a village in L'Aquila municipality located on fluvio-lacustrine sediments, was very seriously damaged with 40 fatalities but nearby Monticchio, on hard rock, was not. Paganica, with eight fatalities, is located on colluvial and alluvial fan deposits. In L'Aquila seismic amplification of geomorphic origin appears to have occurred on convex slopes.

In considering the age and gender pattern of fatalities, it is of note that they are dominated by the 20–29 and over-70s age groups (Fig. 13.3). In this respect, the pattern does not reflect the demographics of L'Aquila province. The prevalence of mortality among old people is a common feature of major earthquakes (Liang et al. 2001), as they are less mobile, less perceptive and more frail than younger people, and they may live, as pensioners, in poorer quality housing. Moreover, the preponderance of female over male victims among the over-70s probably reflects the greater longevity of women, although in the age-range 70–79 it is, in fact, excessively skewed towards women. The peak in the 20–29 age group is interesting and corresponds to findings from the Kobe earthquake of January 1995 (Osaki and Minowa 2001). In the L'Aquila case, it reflects the large number of university students in the city and the high-profile

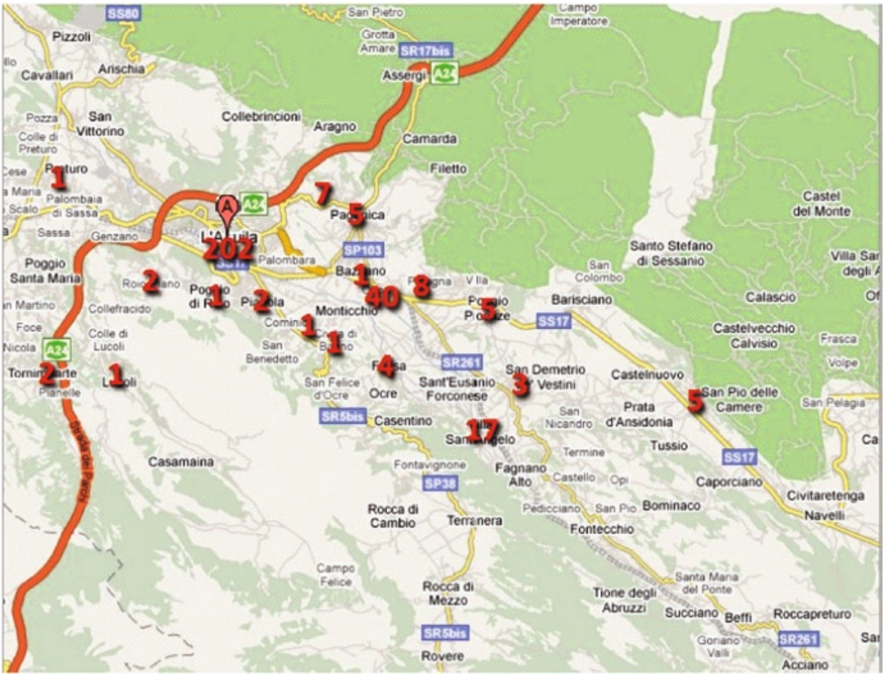

Fig. 13.2 Distribution of earthquake deaths by locality, L'Aquila area

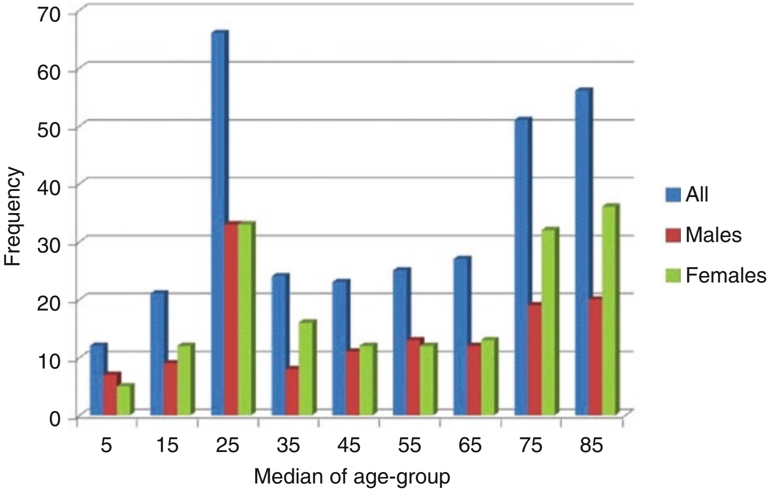

Fig. 13.3 Raw data on deaths by gender and age-group

collapse of student accommodation. Finally, in the 30–39 age-group twice as many women died as men, a finding that begs further investigation.

In general, there is a gender bias in the data that cannot be explained purely by the longevity of women. On average 43 men died to every 50 women. If the over-70s

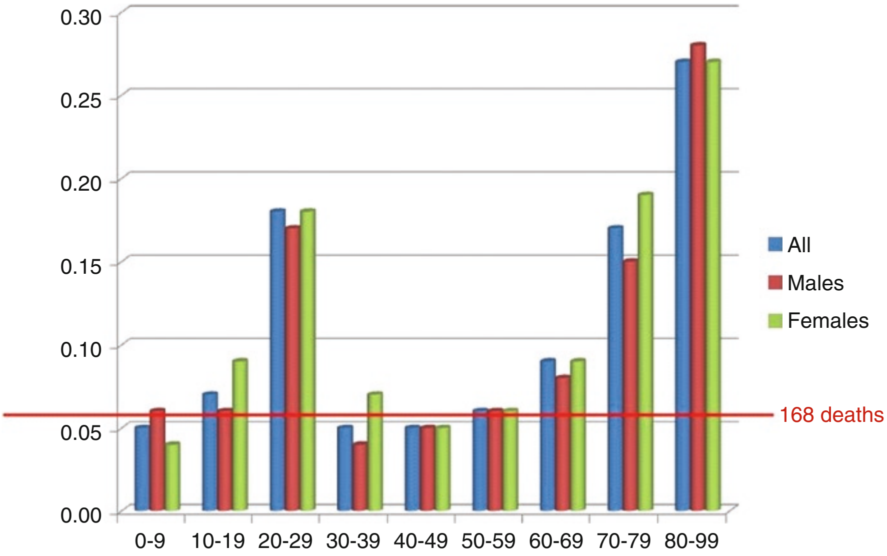

Fig. 13.4 Ratio of deaths to demographic age group

are excluded, the figure remains 47.5 men to 50 women, largely because of the anomalously high mortality among women aged 30–39 years. This is difficult to explain and needs to be investigated in relation to patterns of behaviour.

Figure 13.4 shows the ratio of deaths to the size of the demographic cohort in each age group. If deaths had been evenly distributed across the ages, the ratio would have been constant at 0.055, which would give a total of 168 deaths. Instead, the figure clearly shows the dominance of people of retirement age and in the 20–29 age group, thus producing a higher actual mortality. Females are disproportionately represented in the teens, 30s and 70s. Figure 13.5 amplifies the picture by comparing death tolls predicted according to the demographic age-sex tree with actual mortality among males, females and all victims.

13.3 Scenarios for Earthquakes at Other Times of Day

Since pioneering work in Chile in 1960 (Lomnitz 1970), it has been well-known that aggregate patterns of human behaviour can have a very substantial impact on the totals and patterns of earthquake injuries. In this respect it is interesting to speculate on what the situation would have been if the L'Aquila earthquake had occurred at another time of day or on a different day of the week.

In the L'Aquila earthquake there was an overall death/injury ratio of 0.20 (308 deaths-plus two related heart attack fatalities-and about 1,500 recorded injuries),[1]

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[1] A complete list of victims has been published and repeatedly updated by the newspaper *Il Centro*, see: http//raccota.kataweb.it/terremotoabruzzo/index.php?sorting=morto_frazione,morto_comune, cognome&cerca=cerca

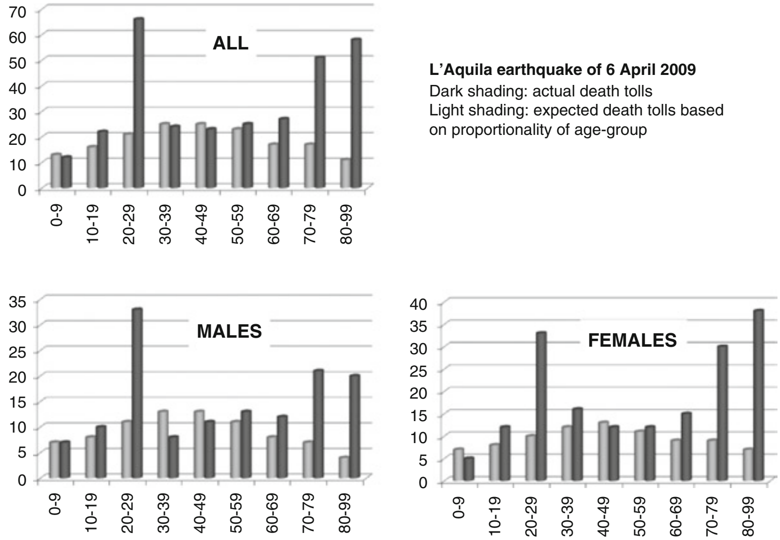

Fig. 13.5 Death tolls predicted from the demographic pattern in relation to actual mortality

which is relatively low for medium-to-large earthquakes (0.33 has been hypothesised-PAHO, 1981). The case fatality rates[2] of 0.17 overall and 0.60 for serious and critical (hospitalised) injuries are low in the first case and high in the second, as the ratio of serious to all injuries was only 0.13, which is somewhat small by comparison with similar earthquakes elsewhere (commonly it might be 0.15–0.25).

Would it have been much different if the earthquake had occurred at another time of day or not on a Sunday night?

First, the time of day: damage to religious buildings was serious enough that if the tremors had occurred during Sunday mass (as happened at Lisbon in 1755 – Chester 2001- and in Irpinia-Basilicata, southern Italy, in 1980-De Bruycker et al. 1985) death tolls among congregations would inevitably have been high. The spontaneous collapse of the vaulting of the Upper Basilica in Assisi after the 1997 Umbria-Marche earthquake swarm crushed four people to death and provided a clear illustration of what could happen to congregations. Moreover, 81 died in the collapse of the church in Balvano, Potenza Province in 1980. Like many churches in the Province of L'Aquila it lacked any significant resistance to seismic acceleration.

Damage to public buildings was substantial but with the exception of the Prefecture (*Palazzo del Governo*), which largely collapsed, it appears to have been less than that inflicted upon vernacular housing. However, cornice collapse and shedding of rubble and roofing material into streets could have caused a significant number of fatalities and injuries (including people in cars) if the streets had been busily occupied rather than deserted, especially in the commercial cores of the city and neighbouring towns. This alone might have led to an even greater death toll.

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[2] 'Case fatality rate' refers to the proportion of injuries that are fatal i.e. (deaths /deaths+injuries).

Significant non-structural damage occurred to the L'Aquila city bus station, a steel-framed building with brick cladding. However, it is only a one-storey building and if it had been full of people there would probably have been significant injuries, although perhaps no deaths.

Serious damage occurred to commercial and industrial premises, but in these, injury tolls would probably have been limited by low density of occupancy. However, at the main hospital in L'Aquila there was significant potential for a greater number of injuries if the earthquake had occurred during the day when many more people would have been using this complex of buildings. As the damage was limited to cladding, ceiling fixtures and walls, no one died in the hospital and that would probably still have been the case if it had been more fully occupied. Nevertheless, injuries might have been concentrated around the main staircase, where damage was more substantial as a result of interference between the two main structural masses of the building, which clearly had different fundamental periods. Had the earthquake been stronger or more prolonged, the stairs might have collapsed and at certain times of day they could easily have been full of people trying to escape the tremors.

13.4 Models of Building Failure

Examination of patterns of damage in the L'Aquila earthquake suggests that it may be possible to create model damage scenarios to help examine the question of *earthquake survivability*. Two examples follow.

Model URM vernacular dwelling. A typical unreinforced masonry (URM) single family vernacular dwelling in a village (such as Onna, Fig. 13.6) or small town of Abruzzo Region might have the following characteristics:

- Two or three storeys with an independent entrance but bounded laterally by other dwellings
- Rubble masonry vertical load-bearing walls 30–40 cm thick consisting of angular limestone fragments bound together with soft lime mortar and cement rendered or covered with stucco
- Hard spots caused by localised repairs, usually about 1–3 m^2 in size
- Weak zones located primarily between apertures, at roof level and at corners, or connected with utility channels and chimney recesses in walls
- A heavy roof consisting of a concrete base or assemblage of concrete, steel joists and hollow terracotta tiles overlain with asphalt sheeting and terracotta pantiles; alternatively one laid upon longitudinal wooden beams of 20–20 cm section and spacing approximately 1.0 m
- Chimneys may consist of precast cement segments that detach and collapse during the shaking

The ancient practice of using courses of tiles in rubble walls, which was started by the Romans and continued until the early twentieth century, could be seen in a minority of buildings in L'Aquila province. It contributed to their cohesion but not to the extent of providing full anti-seismic protection.

Fig. 13.6 Partially collapsed unreinforced brick masonry building (URM) at Onna, L'Aquila municipality

As it weakened heavy masonry walls that lacked basic structural integrity, the practice of carving channels in walls for plumbing and electrical lines (chasements) led to many failures during the 6 April 2009 earthquake. Channels and recesses containing chimneys had a similar effect.

Many failures in URM buildings were connected with mixed construction, for example where rubble masonry in the original building was augmented by brick, cement block or concrete alterations (or even all three). Differing stiffness, compressibility and weight of these components tended to complicate buildings' reactions to seismic stresses.

Model RC vernacular dwelling. A typical reinforced concrete (RC) vernacular dwelling in an Abruzzo town or in L'Aquila city (Fig. 13.7) might be characterised as follows:

- A three-to-five storey multiple-family condominium with a communal entrance and communal stairs
- Use of smooth reinforcing bars (until the 1970s); over-economical usage and poor positioning of stirrups, poor design or setting of bars and stirrups at joints
- A heavy concrete roof with tile overlay
- Hollow-brick infill wall panels that are poorly tied to the frame and may fall out or inwards
- Thin, hollow-brick internal partition walls

As a result of racking of the frame, infill wall panels tended to detach from their frames and fall inwards or outwards, perhaps as a result of fragmentation by X-shaped cracking. Similarly, partition walls fractured and collapsed inside the

Fig. 13.7 L'Aquila city: reinforced concrete (RC) frame building that has suffered mid-floor compression

buildings. Racking also caused pounding, fracturing and torsion at structural nodes. In some cases, the stairs detached from supports and collapsed. Finally, there were numerous instances of heavy damage to plaster, ceilings and fixtures and overturning of furniture.

In L'Aquila there were many examples of incipient (or actual) mid-floor failure in multi-storey RC dwellings (Fig. 13.7). This is indicative of inadequate stiffness, such that inertial effects above were coupled with heavy displacement below. In some cases, the latter may have been affected by seismic wave amplification in alluvial or lacustrine sediments or topographic amplification on convex hillslopes. In many instances this did not lead to collapse of the building but caused much internal damage, especially to partition and infill walls.

With regard to both sorts of dwelling the modern practice of laying terracotta tiles on asphalt sheeting, such that the only things that secure them are weight and interlocking friction, led to the displacement of large numbers of tiles into the street. The lightest form of roofing tile used in Italy (measuring 20 × 36 cm) weighs about 1 kg, which amounts to 15 kg/m^2. Curved pantiles are at least 60–100% heavier than this. It is thus easy for heavy agglomerations of tiles to cascade over the edge of roofs into the street and to take cornices, balcony stonework and façade details with them.

Buildings that were not damaged to the point of partial or total collapse showed surprisingly little breakage of window glass. In other earthquakes this has been a factor in injuring people who rushed outside without adequate footwear. Likewise, collapse of light fittings was not widespread enough to create a significant glass splinter hazard.

13.5 Relating Building Failure to *Earthquake Survivability*

Given the complexity of failure patterns in vernacular housing it is reasonable to suppose that there is no single self-protective behaviour that would be appropriate under all scenarios for damage. Despite the controversy over the predictability of the L'Aquila earthquake (Alexander, unpublished), and notwithstanding the foreshocks, which had been occurring for 6 months before the main shock, it was so unexpected that very few people were mentally or physically prepared when it happened.

The obstacles to immediate and short-term earthquake preparedness fall into six categories:

- *Experience*: people may lack experience or have had no direct contact with the problem
- *Adaptability*: people may fail to adapt or even perceive the need to adapt to the seismic threat
- *Perception* may be insufficient to enable a person to understand the problem well enough to be motivated to act
- *Social*: failure to communicate, associate and learn
- *Economic*: failure or inability to accumulate money and invest in protection
- *Organisational*: lack of social structure and incentive to act

Factors that increase the risk of injury in the case of rapid exit from a building include the following:

- Battering by adjacent structures
- Collapse of URM walls, as coherent slabs or in fragments
- Detachment and fall of tiles from roofs
- Detachment and collapse of pinnacles, balustrades and chimneys
- Demolition by falling masonry of balconies and façade details that juts out
- Separation of URM walls from roofs, with collapse of cornices and upper masonry
- Ejection of infill walls in RC buildings
- Detachment and collapse of corners in URM buildings
- Detachment and collapse of stairs
- Racking distortion of apertures

On the other hand, these are some of the factors that increase the risk of injury in the case of deciding to remain inside a building:

- Battering demolition by detached horizontal members (wooden roof beams and steel floor joists)
- Torsion, distortion and shattering of nodes in RC buildings
- Inward collapse of roofs
- Bulging and reticular cracking of walls, with detachment of rendering and stucco and eventual collapse of the structure

- X-shaped, diagonal or reticulated cracking in the weak zones between apertures
- Implosion of infill walls in RC buildings and collapse of internal partition walls
- Damage to ceilings and internal fittings and overturning of furniture

In heavily damaged buildings in L'Aquila there was little indication that the "triangle of life" (Copp 2005) would have helped to save people from crush injuries or being buried by dust and rubble. Neither would sheltering under tables or desks. The "triangle of life" has been vigorously promoted by the American Rescue Team (see www.amerrescue.org) but equally vigorously contested by other protagonists (Lopes 2004). It involves sheltering next to large, robust objects that block the collapse of beams and slabs and leave a triangular cavity in which a person may shelter (relatively) unscathed. In general, complete collapse of a frame building may leave some void spaces, perhaps 10–15% of the resulting mound of rubble, but they can easily fill with cement, gypsum or mortar dust and fragments. Examination of the partial and total collapse of buildings in L'Aquila city and Onna village suggested that the "triangle of life" approach would have been ineffective as there were few adequate cavities.

There is some- albeit circumstantial- evidence that when buildings were being heavily damaged the best spontaneous action would have been to retreat further inside. Running into the street would put people significantly at risk from falling masonry or the collapse of stairways. In any case, rapid egress was made difficult by doors that jammed as a result of racking distortion.

In consideration of the types and levels of damage caused in the L'Aquila earthquake, risk of death or injury can be related to damage level on the following five-point scale:

1. *Damage level*: minimal indoor damage to walls, fixtures and fittings.
   Personal risk: for most people, prudent behaviour ensures freedom from injury.
2. *Damage level*: significant damage to structure and fittings.
   Personal risk: risk of moderate injury but no significant risk of death.
3. *Damage level*: pervasive damage and collapse of architectural details.
   Personal risk: significant risk of serious injury but low risk of death.
4. *Damage level*: major damage and limited partial collapse.
   Personal risk: strong risk of serious injury and significant risk of death.
5. *Damage level*: collapse of more than 50% of the structure.
   Personal risk: limited probability of survival.

Independently of any question of making buildings safer by retrofitting them, it would be possible to create a strategy to survive earthquakes while at home-at least under ideal circumstances of perception and commitment of householders. This would involve making a simple assessment of the probable seismic behaviour of a vernacular dwelling and planning to react accordingly. The following steps are proposed:

- Identify and avoid the riskiest forms of behaviour, such as running blindly out of the house.
- Develop criteria to identify the safest place in the house- i.e. the most robust place with the least risk of collapse- in the light of the following considerations:
  - Potential for detachment and displacement of roof tiles or the entire roof
  - Stability of cornices and external balusters
  - Degree of support of staircases
  - Possibility of battering interference with adjacent buildings that are different in size, shape and construction and thus have different fundamental periods
  - Heterogeneity of materials and potential for interference or complex behaviour
- Create an egress procedure, considering the difficulties of exiting a building in an environment characterised by high levels of damage and precariousness. The procedure should identify the nearest safe refuge and assembly area.
- Identify the most dangerous places in the house and plan to withdraw from them.
- Create a mutual support network of relatives, friends and neighbours.
- Assemble a cache of small-scale emergency equipment and materials (torch, radio, hard hat, water sterilisation pills, etc.).
- Instruct and train family members and ensure that drills are practised.

An elementary school in the middle of the urban area in Onna was of new construction and resisted the earthquake without sustaining damage. Its presence was an indication of the importance of such buildings as the potential location of command posts, advance medical posts (first-aid stations), points of refuge for the population and reception centres for people who cannot return home. Ideally, each neighbourhood or village should have such a building. It should specifically be designated as multi-function and should be equipped accordingly.

13.6 Conclusions

The L'Aquila earthquake of 6 April 2009 was a moderate seismic event that created a disproportionate amount of damage and number of casualties. Clearly, the tremors exploited situations of high vulnerability and revealed considerable unpreparedness on the part of the Aquilan population. The "window of opportunity" represented by increased sensitivity in the wake of disaster needs to be exploited by increasing the level of earthquake readiness and reducing seismic vulnerability. This will involve correcting evident faults in buildings, especially those noted above. It could also involve developing quick but serviceable means of assessing risk of injury and recommending self-protective strategies, with particular reference to the most vulnerable groups of people. The next stage of this research will involve surveys of the homeless survivors in order to find out how they reacted to the earthquake, what perception of danger they had and what degree of safety they thought their houses offered.

Acknowledgments I thank the Earthquake Engineering Research Institute (EERI) and American Society of Civil Engineers (ASCE) for the opportunity to participate as a member of their reconnaissance teams in L'Aquila, and also Dr Fausto Marincioni for valuable discussion and assistance with the work on which this paper is based.

Chapter 14
Major Factors Controlling Earthquake Casualties as Revealed via a Diversified Questionnaire Survey in Ojiya City for the 2004 Mid-Niigata Earthquake

M. Koyama, S. Okada, and Y. Ohta

Abstract An extensive questionnaire survey on various seismic effects for inhabitants, dwellings, and social settings was conducted in an area of Ojiya city affected by the 2004 Mid-Niigata earthquake. The investigation takes into consideration repeated aftershock effects; however, in this report we focus on injuries during the main shock event, which injured most victims. To obtain details about the causes of injuries, the relationships of the injuries were investigated using the following four dimensions: (1) the scale of dwelling damage grade by seismic intensity; (2) the dangers of weapons such as furniture overturned and/or fallen debris; (3) what type of injury is incurred and which body part is injured; and (4) variation of injury rate by household structure. Traditional injury mitigation strategies focusing on building damage are restated as anti-death strategies on the basis of these results. However, injury mitigation strategies are also important problems from a QOL (quality of life) point of view. Through this survey, various cross sections of the injury process become clear. The results indicate that a total risk control strategy including lifestyle is required for the life-loss reduction strategy. A continuous examination of this research would lead to the construction of a numerical estimation model for individual injury.

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14.1 Introduction

The 2004 Mid-Niigata prefecture earthquake occurred on 23 October at 17:56 (JST). The epicentre was located at latitude 37.29° north and longitude 138.87° east at a depth of 13 km. The magnitude of the earthquake was 6.8 (Mjma). Figure 14.1 shows the epicentre location and an isoseismal map of Niigata Prefecture. Table 14.1 shows a comparison between JMA (Japan Meteorological Agency) and MSK seismic intensity scales.

A full-scale questionnaire survey was conducted for obtaining information about the relationship between various seismic effects for inhabitants, dwellings, and social settings. The target area was Ojiya city, an area affected by this earthquake. Questionnaire sheets were collected by mail. The purpose of this study was to determine the earthquake's injury mechanism. Many estimation models of earthquake casualties have been developed using the relationship between human damage and building damage grades (e.g., Ohta and Okazaki 1998, Tabata and

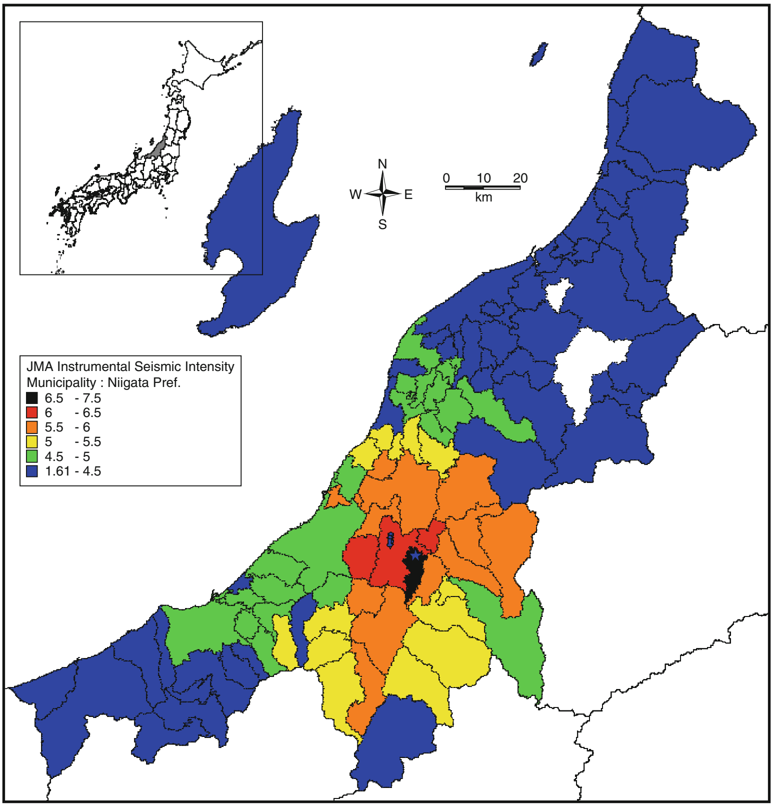

Fig. 14.1 Epicentre location and an isoseismal map of Niigata prefecture

Table 14.1 Comparison between JMA and MSK seismic intensity scales

JMA	3	4	5 Lower	5 Upper	6 Lower	6 Upper	7
(instrumental)	2.5–3.5	3.5–4.5	4.5–5.0	5.0–5.5	5.5–6.0	6.0–6.5	6.5–7.5
MSK	IV V	VI	VII	VIII	IX		X XI XII

Okada 2006). A dwelling collapse kills people in most cases; therefore, these models are effective for developing an anti-death strategy. Nonetheless, from a QOL (quality of life) point of view, most of us would accept that an injury mitigation strategy is also an important concern. Nachi and Okada (2007) pointed out that information about the relationship between living conditions, human behavior, and injury is required for an injury mitigation strategy. At present, only a small number of studies consider the effect of living conditions and human behavior on injuries (e.g., Okada et al. 2006; Nachi and Okada 2007). Okada et al. (2006) interviewed each family member about their behaviour and injury situation from the start of the earthquake to the time of their escape.

This was very valuable for understanding the injury mechanism; however, these samples are not sufficient because collecting a large amount of data is difficult using an interview survey. The survey reported here was conducted to obtain details about the injury mechanisms. Questions asked relating to the injury mechanism were as follows: (1) Place of injury–Where were you injured? (2) Weapon–What object caused the injury? (3) Injured part of body–Which part of the body was injured? (4) Injury grade–Were you an outpatient, inpatient, or not a patient after the earthquake? (5) Injury type–What type of injury did you have? (6) Family structure–Age and sex of each family member at home. (7) Human behaviour–What did you do during the earthquake? The results of this study will be valuable for developing life-loss reduction strategy.

14.2 Methods

14.2.1 Investigation

The questionnaire survey was carried out at Ojiya city in September, 2005. Questionnaire sheets were distributed to each household via local self-governing bodies with the city newsletter and collected by mail. Ojiya city is located in an intermediate and mountainous area in the north-central district of Japan. The population is approximately 41,000. Its size and geographical conditions are typical for Japan. We distributed 12,000 questionnaire sheets to all households and 4,431 sheets were collected. This is one of the highest density surveys of its kind. Our questionnaire sheet was developed based on Okada et al. (2006). This

Table 14.2 Composition of questionnaire

Part 1: Earthquake shaking and building structure : 47 questions
To estimate JMA scale seismic intensity (Main shock, by household)
Building's base, shape, degree of deterioration and so on… (by household)
Part 2 : Family make-up and damage, etc. : 48 questions
Damage to dwelling (Main shock and aftershocks, by household)
Each family member's behaviour and injury (Main shock and aftershocks, by each family member)
Evacuation (Main shock and aftershocks, by each family member)
Rebuild dwelling and life (by household)

and Okada et al. (2006) studies in the investigation method are complementary, such as interviews and mail surveys. The questionnaire sheet consisted of two parts as shown in Table 14.2, with the underlined sections being injury-related questions. The investigation takes into consideration repeated aftershock effects; however, we focus on the injury mechanism during the main shock.

14.2.2 Statistical Analysis

We analysed the data using the statistical package R version 2.9.2 (www.r-project.org/). To obtain details of the injury mechanism, the relationship with the injury was investigated using the following four aspects: (1) relationship between individual attributes and injury; (2) relationship between seismic intensity, damage to dwelling, and injury; (3) relationship between weapon, human behaviour, situation, and condition of injury; (4) relationship between household structure and injury. Nineteen inhabitants were killed in Ojiya city; however, questionnaire sheets were not collected from these households.

14.3 Results

14.3.1 Sampling Distribution

The male to female ratio of respondents is 48:52 and 49:51 by census. The responders' female ratio is slightly higher than the census value. Figure 14.2 shows histograms of age obtained by census and collected data. The response rate of the working population is lower than the older generation and the male rate is lower than the female rate, because the earthquake occurred in late afternoon on a weekday. In addition, the range of age groups as '0–9', '35–44', '45–54', '55–64', '65–74' is 10 years and the range of age groups as '10–14', '15–19', '20–24', '25–29', '30–34' is 5 years. Therefore, apparent frequencies are lower in the latter case.

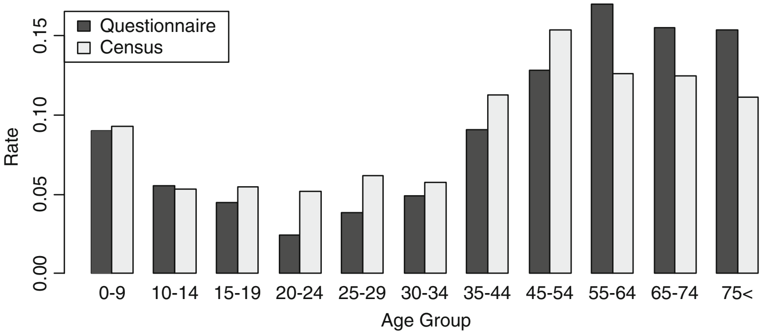

Fig. 14.2 Age distribution

14.3.2 Individual Attributes and Injury

People who were at home during the earthquake are the targets of this section. The relationship between gender and injury is shown in Fig. 14.3. This figure indicates that the female injury rate is higher than the male injury rate, especially in the late twenties. The relationship between age and injury is shown in Fig. 14.4. This figure indicates that the injury rate is higher with age and injury rate distribution of daily life accidents has a double hump (infants and elderly) (e.g., (Nobuhara and Miyano 1996; Miyano and Sumiyoshi 1999). Our result does not differ from the existing studies.

14.3.3 Seismic Intensity, Damage to Dwellings and Injury

Questions for estimating seismic intensity (Ohta et al. 1998) are included in our survey; therefore, one seismic intensity value 'equivalent of JMA scale' was estimated by one household. Table 14.1 shows the comparison between JMA and MSK seismic intensity scales. The Aza unit isoseismal map of Ojiya city and the histogram of seismic intensity are shown in Fig. 14.5. Aza means the smallest block in Japan. Seismic intensities (SI) in Fig. 14.5 are median values of households in each Aza. Seismic intensity in Ojiya city ranged almost '6 Lower' to '7'. '6 Upper' area made up 56% of Ojiya city. Seismic intensity values of '6 Lower', '6 Upper' and '7' are also indicated in Table 14.1. The most simple injury mechanism during an earthquake is as follows. Ground motion causes building and property damage. Then the damaged building or property causes injury. Something that causes injury is called a weapon. Weapons during an earthquake are divided into two major groups. One has roots in damage to dwellings and the other one is interior objects like furniture. The following injury factors are picked up in this survey: (1) building structural members like columns, beams, wall, and ceiling; (2) under an overturned piece of furniture; (3) a hot object like a splash of hot water; (4) falling down; (5) being hit by a falling object like furniture; (6) sharp objects like broken glass, dishes, and metal.

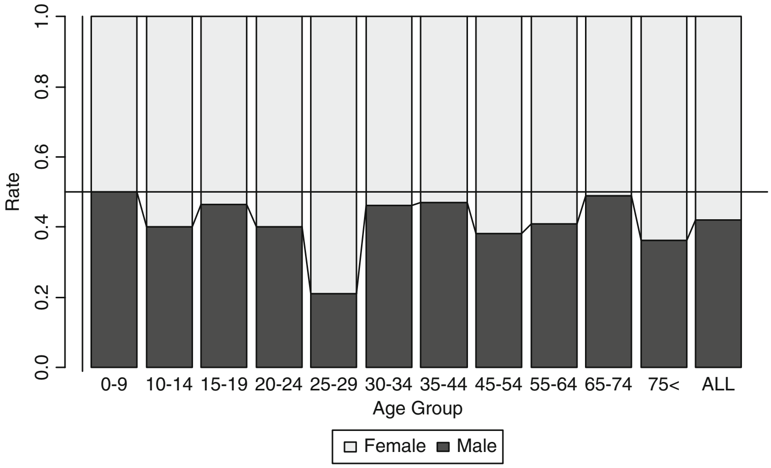

Fig. 14.3 Male to female ratio of injured

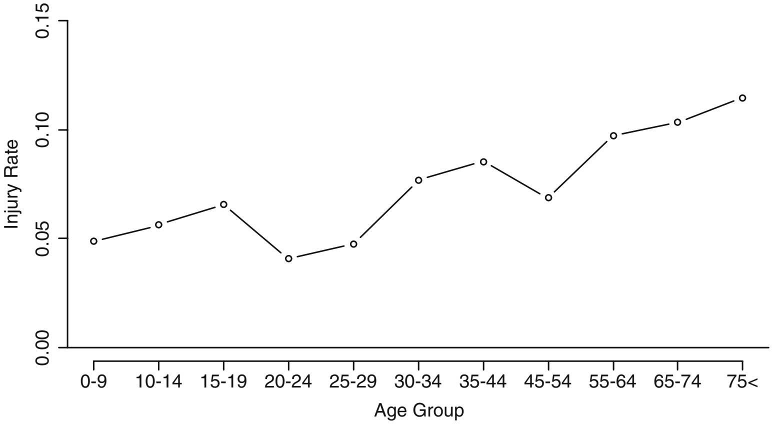

Fig. 14.4 Injury rate by age group

Figure 14.6 shows the damage rate of wooden houses by each seismic intensity range. The sample's seismic intensity falls in the Aza's median value. Intensity ranges are shown on the horizontal axis for plus and minus 0.3. The grade from D0 to D6 is the 'Damage Grade' for wooden houses (Okada and Takai 1999) in Fig. 14.7. A large suffix number means more severe damage. Figure 14.6 shows that stronger the seismic intensity, the more serious the damage. Transit of injury rate by seismic intensity and damage of wooden houses is shown in Fig. 14.8. It indicates that the stronger the seismic intensity, the higher the injury rate, especially causing severe damage to dwellings. In the figure, the injury rate decreases at more than 6.7; however, this is ruled out by the laws of physics. There are two possible reasons at

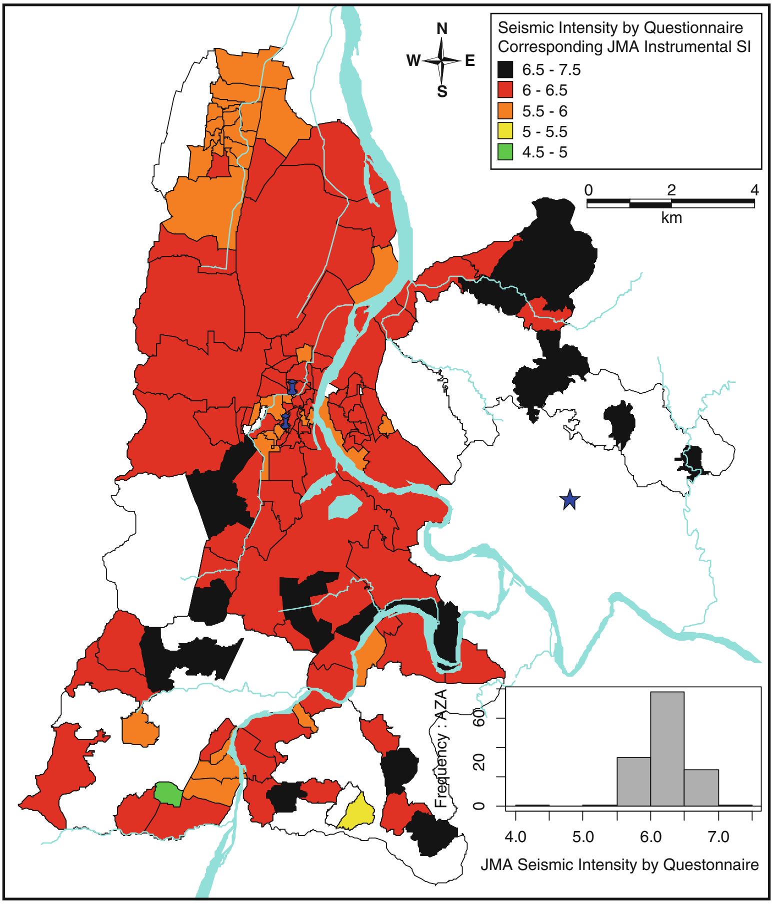

Fig. 14.5 *Aza* unit isoseismal map of Ojiya city and histogram of seismic intensity

the present time. The first one is, as mentioned above, is that the amount of sample data by seriously damaged households is insufficient. The second one is a statistical problem. Generally, at the edge of seismic intensity distribution, sample density is low; therefore, there is a possibility that injury rate is not reflective of population in the high intensity range. Whether this is the case or not, additional analysis is required.

Figure 14.9 shows the change of injury rate by seismic intensity and weapons. The figure shows that the stronger the seismic intensity, the higher the injury rate, especially with high risk weapons. This indicates the same trend as Fig. 14.8. The problem of the injury rate decreasing at high intensity range is as noted above. Transit of the injury rate by seismic intensity and injured place at home is shown in Fig. 14.10. The injured place indicates the location of the most serious injuries. These are: (1) a room one stayed in during the earthquake, (2) stairs in a building,

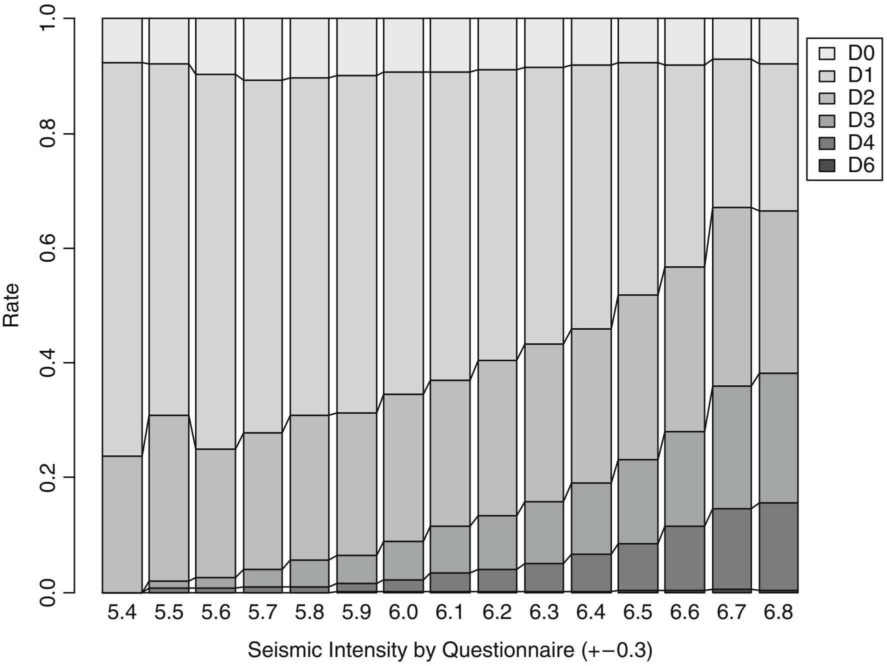

Fig. 14.6 Damage rate of wooden houses by seismic intensity

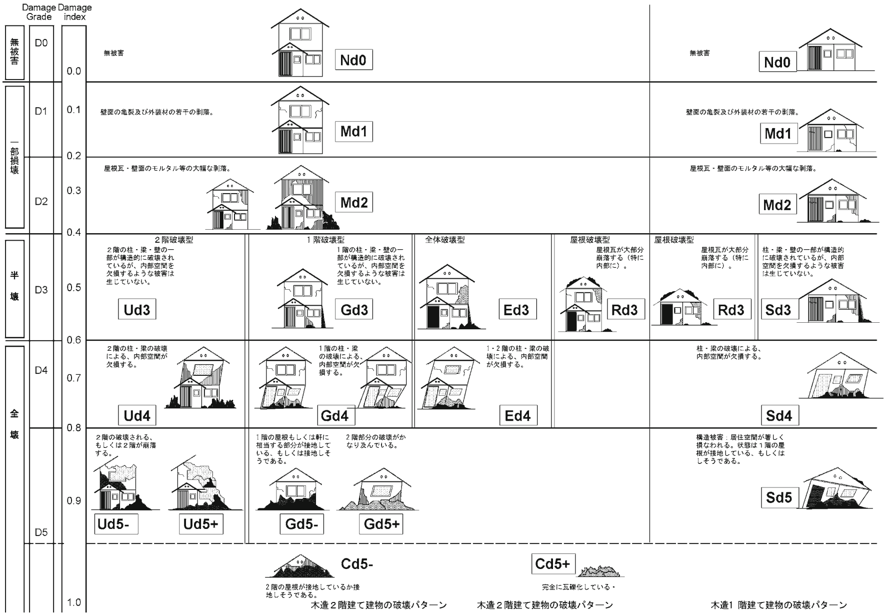

Fig. 14.7 Damage grade of wooden houses (Okada and Takai 1999)

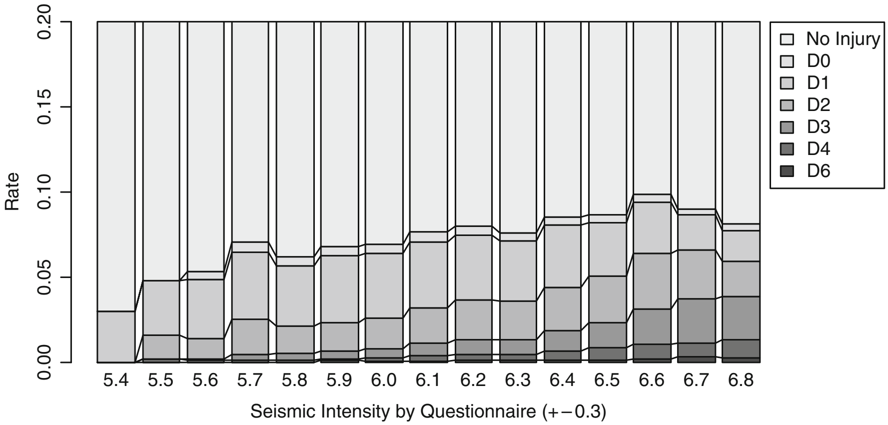

Fig. 14.8 Change in injury rate by seismic intensity and damage of wooden houses (Enlarged vertical axis from 0.0 to 0.2)

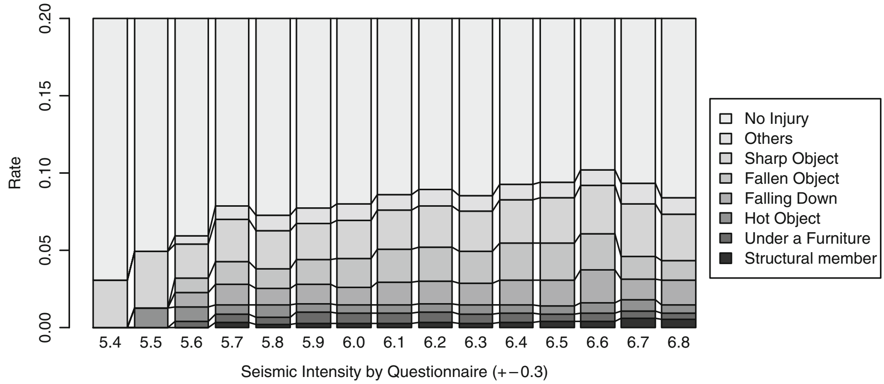

Fig. 14.9 Changes in injury rate by seismic intensity and weapon (Enlarged vertical axis from 0.0 to 0.2)

(3) outside stairs, (4) uneven surface like a boundary between the rooms, (5) entrance, (6) passage way connecting the rooms, (7) kitchen, (8) bathroom and washroom (in Japan, bathroom means a room that has only a bathtub and washing place and washroom means a room that has a washbasin, furniture, and a washing machine), and (9) lavatory (in Japan, lavatory means a room that has only a toilet). The figure shows that the stronger the seismic intensity, the higher the risk of ‘Entrance’ and especially ‘Kitchen’. One reason for the high injury rate of ‘Kitchen’ is because the earthquake occurred during dinner time.

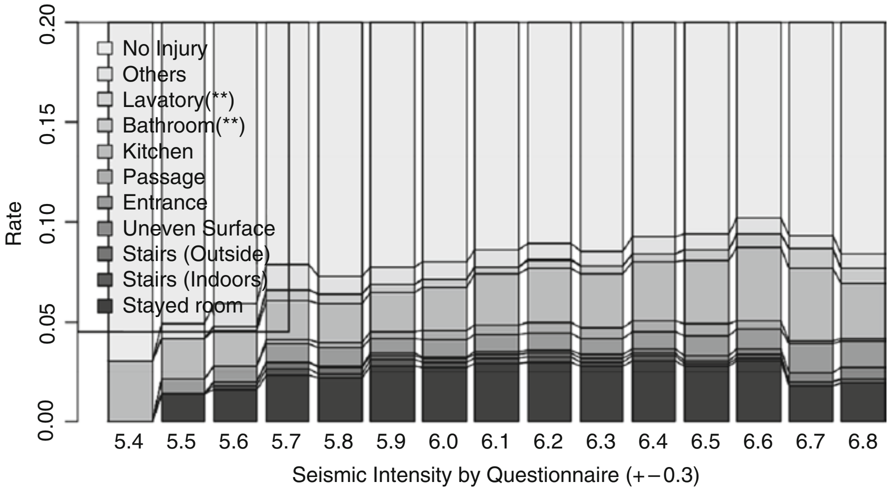

Fig. 14.10 Changes in injury rate by seismic intensity and injured location (Enlarged vertical axis from 0.0 to 0.2)

14.3.4 Details of Injury

Injury rate by damage grade and weapons is shown in Fig. 14.11. The figure shows that the more severe the grade value, the higher the injury rate. Heavy furniture and structural members cause serious injury. In the case of high risk weapons, injury rates increase as the seismic intensity becomes higher. The increasing trend is moderate from D0 to D4; however, it increases sharply at D6. D6 means total collapse shown in Fig. 14.7; therefore, there are crucial differences of both safety and allotted time to evacuate, between D6 and others patterns of damage. In addition, there is no sample of D5.

Figure 14.12 shows the details of weapons by each injury location. The case of multiple injuries, 'injury location' means the place of the most severe injury. Characteristics of weapons by each injury location are as follows. In the case of 'Living Room', the injury rate is in the following order: 'Fallen Object', 'Sharp Object', 'Under Furniture', 'Falling Down', 'Structural Member', and 'Hot Object'. In the case of 'Stairs (Indoors)', the injury rate is in the following order: 'Falling Down', 'Sharp Object', 'Structural Member', and 'Fallen Object'. In the case of 'Stairs (Outside)', the tendency is similar to 'Stairs (Indoors)' without 'Fallen Object'. In the case of 'Uneven Surface', the injury rate is in the following order: 'Falling Down', 'Fallen Object' and 'Sharp Object'. In the case of 'Entrance', the injury rate is in the following order: 'Fallen Object', 'Falling Down', and 'Sharp Object'. In the case of 'Passage Way', the injury rate is in the following order: 'Sharp Object', 'Falling Down', 'Fallen Object', 'Under Furniture' and 'Structural Member'. In the case of 'Kitchen', the injury rate is in the following order: 'Sharp Object', 'Fallen Object', 'Hot Object', 'Falling Down', 'Under a Furniture' and 'Structural Member'. In the case of 'Bathroom', the injury rate is in the following order: 'Sharp Object',

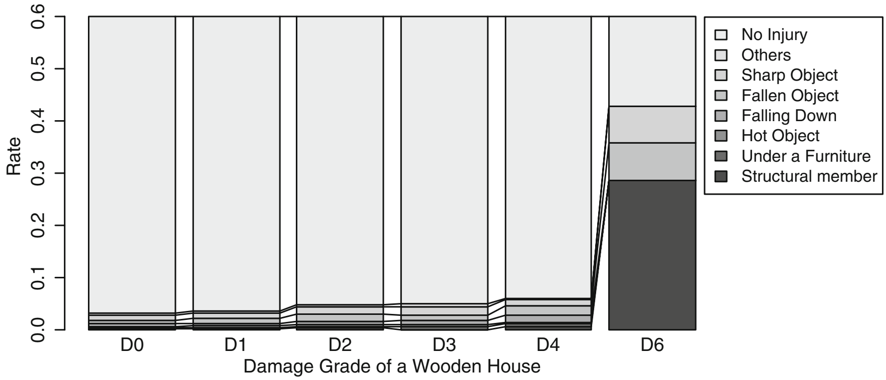

Fig. 14.11 Injury rate by damage grade and weapons (Enlarged vertical axis from 0.0 to 0.6)

Fig. 14.12 Details of weapons by each injury location (NA means no answer)

‘Structural Member’, ‘Fallen Object’, ‘Falling Down’ and ‘Under Furniture’. Here, ‘Bathroom’ includes washroom. As mentioned above, in Japan, ‘Bathroom’ means a room that has only bathtub and washing place and ‘Washroom’ means a room that has washbasin, furniture, and washing machine. In the case of ‘Lavatory’, injury occurred only by ‘Falling Down’. As stated above, in Japan, ‘Lavatory’ means a small room that has only a stool. These places are divided into two types as a room and pathway. Major weapons are ‘Furniture’, ‘Fallen Object’ and ‘Sharp Object’ in the room. Major weapons are ‘Falling Down’ and ‘Sharp Object’ in the pathway. Major weapons are ‘Hot Object’ and ‘Sharp Object’ in the kitchen, because of the cooking stove and furniture, where fragile glass, cups, and dishes are stored.

Figure 14.13 shows details of the injured part of the body by each weapon. In the case of ‘Craniocervical Region’, the injury rate is in the following order: ‘Fallen Object’, ‘Under Furniture’, ‘Sharp Object’, ‘Falling Down’, and ‘Structural Member’. In the case of ‘Face’, the injury rate is in the following order: ‘Fallen Object’, ‘Falling Down’, ‘Structure Member’, ‘Under Furniture’ and ‘Sharp Object’. In the case of ‘Thoracoabdominal’, the injury rate is in the following order:

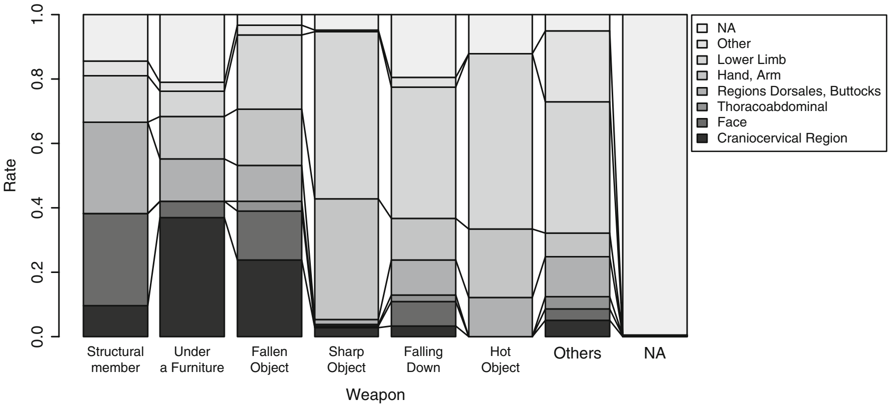

Fig. 14.13 Details of injured part of the body by each weapon (NA means no answer)

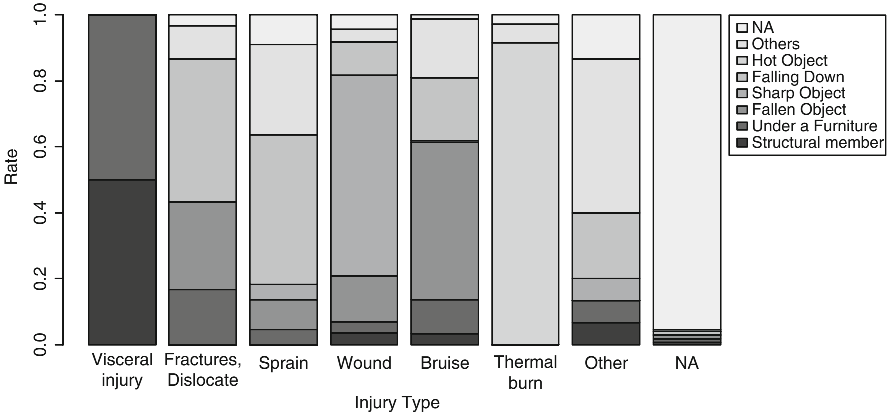

Fig. 14.14 Details of weapons by injury type (NA means no answer)

'Fallen Object', 'Falling Down' and 'Sharp Object'. In the case of 'the back and dorsal region', the injury rate is in the following order: 'Fallen Object', 'Falling Down', 'Structural Member', 'Under a Furniture' and 'Hot Object'. In the case of 'Arm', the injury rate is in the following order: 'Sharp Object', 'Fallen Object', 'Falling Down', 'Hot Object' and 'Under a Furniture'. In the case of 'Lower Limb', the injury rate is in the following order: 'Sharp Object', 'Falling Down', 'Fallen Object', 'Hot Object', 'Under Furniture' and 'Structure Member'. Characteristics of relationships between weapon and injured part of body are summarised as follows. First, the upper half of the body is at high risk of injury by 'Fallen Object' and 'Furniture'. Second, the lower half of the body is at high risk of injury by 'Sharp Object' and 'Falling Down'. Third, arm and lower limb are at high risk of injury by 'Sharp Object'. Fourth, the abdomen is at high risk of injury by all weapons.

Figure 14.14 shows the details of weapons by injury type. 'Visceral Injury' is caused by 'Structural Member' and 'Under Furniture'. 'Falling Down' is the most

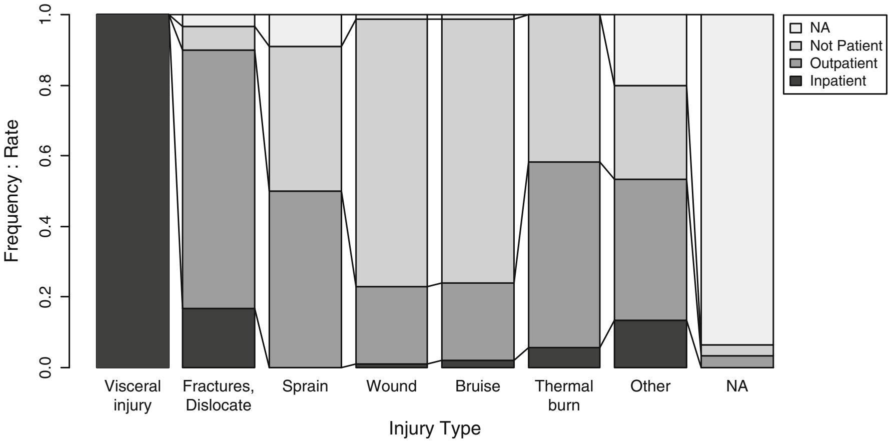

Fig. 14.15 Details of treatment by injury type (NA means no answer)

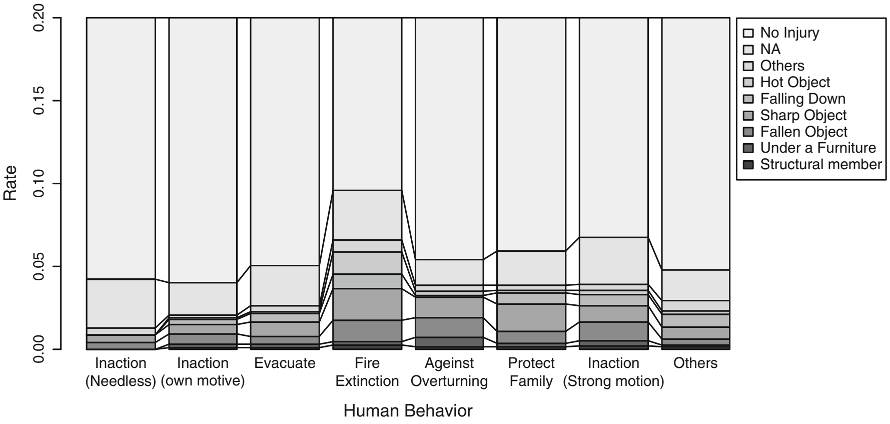

Fig. 14.16 Injury rate by weapons and human behaviour (Enlarged vertical axis from 0.0 to 0.2)

common cause of ‘Fractures, Dislocations’, followed by ‘Fallen Object’ and ‘Under Furniture’. ‘Falling Down’ is the most common cause of ‘Sprain’, followed by ‘Fallen Object’, ‘Sharp Object’, and ‘Under Furniture’. ‘Sharp Object’ is the most common cause of ‘Wound’, followed by ‘Fallen Object’, ‘Falling Down’, ‘Under Furniture’, and ‘Structure Member’. ‘Fallen Object’ is the most common cause of ‘Bruise’, followed by ‘Falling Down’, ‘Under Furniture’, ‘Structure Member’, and ‘Sharp Object’. ‘Thermal Burn’ is only caused by ‘Hot Object’. The details of treatment by injury type are shown in Fig. 14.15. The most serious injury is ‘Visceral Injury’, following by ‘Fractures, Dislocations’, and ‘Thermal Burn’. Figures 14.14 and 14.15 tell us structural member and heavy furniture are causes of serious injury with threat to life.

Injury rate by weapons and human behaviour is shown in Fig. 14.16. Human behaviors classified as follows: (1) ‘Inaction (Needless)’ indicates the person did not do anything, (2) 'Inaction (Own Motive)' indicates the person stayed there by own volition, (3) 'Evacuate' indicates person evacuated to the outside, (4) 'Fire Extinction' indicates turning off a cooking stove, heater, and so on, (5) 'Against Overturning' indicates a person held furniture to stop it from overturning, (6) 'Protect Family' indicates person protected, rescued, and confirmed the safety of one's family, (7) 'Inaction (Strong Motion)' indicates person could do nothing because of the strong earthquake motion. The case of 'Fire Extinction' has the highest injury rate, followed by 'Inaction (Strong Motion)', 'Protect Family', 'Against Overturning', 'Evacuate', 'Inaction (Own Motive)', and 'Inaction (Needless)'.

As seen above, in cases of people who were injured averting action and who could not do anything because of strong motion, the injury rate is higher than the cases of actively doing nothing. People have long been lectured from childhood in Japan to 'Put the fire out during an earthquake'. Because of the circumstances, the case of 'Fire Extinction' has the highest injury rate. In addition, nowadays, intelligent gas meters are installed in almost all households. This intelligent meter stops gas automatically when it is exposed to strong motion. Therefore, injury risk during fire-extinction activity is higher than others. Presently, fire-extinction activity is not recommended during an earthquake. Then, the relationship between human behaviour and weapon is explained. In the case of 'Fire Extinction', high injury risk from 'Hot Object' is well known; however, the risk from 'Sharp Object', 'Fallen Object', and 'Falling Down' are also high. In the other cases, the main causes of injury are 'Falling Down', 'Sharp Object', and 'Fallen Object'.

14.3.5 Household Structures and Injured

Age distributions of 'Single' and 'Multifamily' are shown in Fig. 14.17. Here, 'Single' means someone staying home alone during an earthquake. Therefore, strictly speaking 'Single' does not mean a single family. 'Multifamily' means

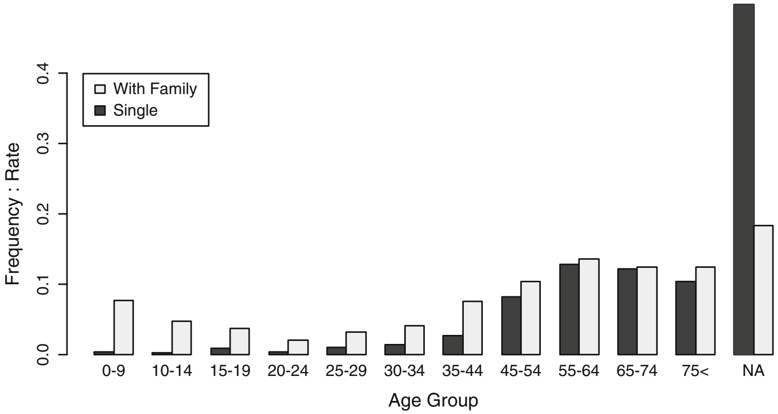

Fig. 14.17 Age distributions of 'Single' and 'Multifamily' (NA means no answer)

someone remained at home with others during the earthquake. The feature of 'Multifamily' distribution is similar to all responder's distribution in Fig. 14.2. On the other hand, 'Single' has high percentages of older generation and no answer (NA). The reason 'Single-NA' ratio is especially high is because recently, the Japanese have become increasingly concerned of their privacy. In the future, questionnaire methods will be required to account for this growing trend. Injury rate of 'Single' is 13.5% and 'Multifamily' is 8.2%. These injury rates by age bracket are shown in Fig. 14.18. 'Multifamily' injury rate gradually increases as the age increases. There is no injury under 30 years old for 'Single'. And the injury rate 'Single over 29 years old' is higher than 'Multifamily'.

Relationships between injury rate, living environment, and human behaviour are explained in the following section. Here, living environment means indoor conditions and household structure. At this time, household structures are 'Single' or 'Multifamily', 'Under 30 years old', or 'Over 29 years old'. Figure 14.19 shows the

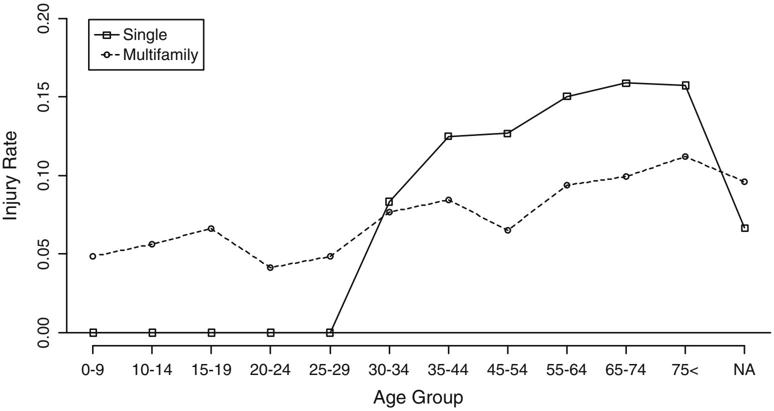

Fig. 14.18 Injury rates by age bracket and family structure (NA means no answer)

Fig. 14.19 Frequencies of damage grade by household structure

frequencies of damage grade of a wooden house by household structures. Frequency of D1, D2, and D3 are almost the same for all cases. The features of 'Multifamily' and 'Single, Over 29' are generally the same. The total building damage rate of 'Single, Under 30' is lower than the others. There is no damage at D4 and D6 in the case of 'Single, Under 30'. Examining the relationship between building damage and injury in Fig. 14.19, the injury rate of 'Single, Under 30' is the lowest and 'Single, Over 29' is nearly equal to 'Multifamily'.

Frequencies of total floor area are shown in Fig. 14.20. Both the cases of 'Multifamily', '140 m^2<' make up 56% and the others are from 6% to 12%. In the case of 'Single, Over 29', '140 m^2 <' is 39% and both cases of '<80 m^2' and '120 m^2' are 16%. In the case of 'Single, Under 30', both '140 m^2 <' and '<80 m^2' are 28% and the shape is indicative of a bimodal distribution. One of the reasons for this is that 'Single' includes the case of multifamily that stayed alone during the earthquake. Generally, the wider the house and the older the inhabitant's age, there is more furniture. Furniture is also a weapon during an earthquake; consequently, the living environment-dependent injury risk increases as total floor area and inhabitant's age increase. Therefore, the reason the injury rate of 'Single, Under 30' is lower than the others in Fig. 14.18 is convincing. The reason for the injury rate of 'Single, Upper 29' is not explained by the living environment at present.

The injury rate by human behaviour and household structure is shown in Fig. 14.21. In the cases of 'Multifamily', injury rate of 'Over 29' is higher than 'Under 30'. The injury rate of 'Single, Over 29' is higher than 'Multifamily, Over 29'. For the case of over 29 years old, we confirmed that there is a significant difference between single and multifamily. We used tests of equal or given proportions (prop.test) function of R for each human behaviour case. The *P*-value is shown in Table 14.3. As a result, there is significant difference in the cases as 'Inaction (Own Motive)', 'Evacuate', 'Fire Extinction', and 'Inaction (Strong Motion)'. In addition, the features of human behaviour frequency do not differ from each other.

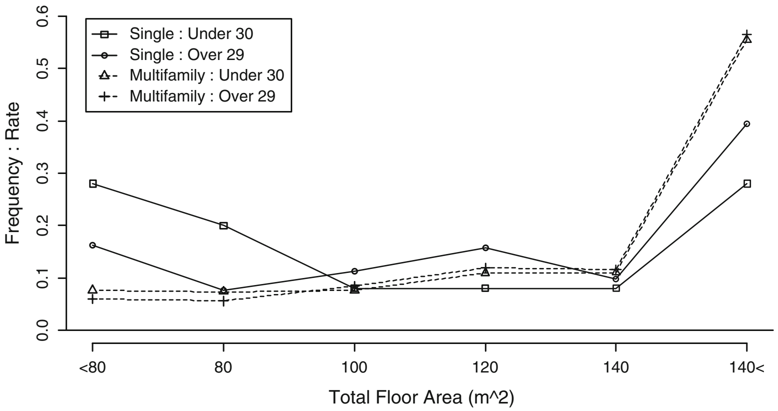

Fig. 14.20 Frequencies of total floor area

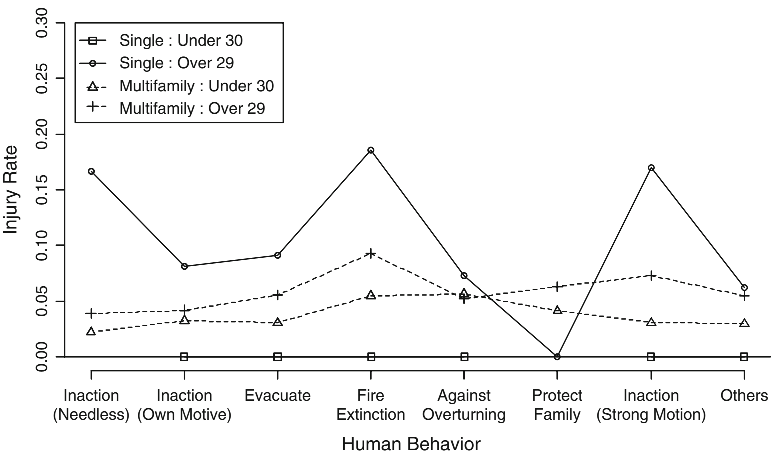

Fig. 14.21 Injury rate by human behaviour and household structure

Table 14.3 *P*-value table of human behaviour

Human Behaviour	*P*-value	
Inaction (Needless)	0.1837	
Inaction (Own Motive)	0.02359	*
Evacuate	0.009382	**
Fire Extinction	0.01183	*
Against Overturning	0.8302	
Protect Family	0.4626	
Inaction (Strong Motion)	0.00000568	**

14.4 Discussion

The purpose of this study was to determine an injury mechanism during an earthquake. We investigated not only the relationship between damage to dwellings and injury but also injury detail and relationship between injury and household structure. Here, injury detail means relationship among weapons, human behaviour, situations, and type of injury. Through the survey, we reported various cross sections of the injury process as follows; (1) how dwelling damage grade corresponds to seismic intensity; (2) what weapon is the most dangerous in each location, what kind of injury results, and what part of the body is injured; (3) variation of injury rate by household structure. These results are provided as unconventional information for developing an injury estimation model focused on individuals. The results and the derived knowledge are summarised as follows. Weapons are divided into two types: building damage related and others. Aspects of injury from the above two types of weapons differ from each other. The weapons related dwelling damage causes serious injury; therefore, we reconfirmed that improving anti-earthquake performance of housing is indispensable to preserving life. Traditional injury mitigation strategies focused on building damage; this should be restated as a life-loss reduction strategy on the basis of these results. However, injury mitigation strategy is also an important problem from a QOL point of view.

With the damage grade D0, D1, D2, D3, and D4 (Fig. 14.7), the relationship between damage grade and injury rate cannot be confirmed. Instead, the injury situation is changed by the living environment and human behaviour. One example is the relationship between three inactions and injury-averting actions (Fig. 14.16). Here, there are clear differences among the injury situation of three 'Inactions' as 'Needless', 'Own Motive', and 'Strong Motion'. The injury rate of the first two inactions is comparatively low and the latter rate is high. The feature of 'Inaction (Strong Motion)' is similar to injury-averting action instead. Each spatial hazard of three 'Inactions' is considered as follows. In the cases of the first of two 'Inactions', people could remain in a safe space or the shaking was not so strong. In the case of the latter 'Inaction', people stayed in a dangerous place or the shaking was very strong. The case of the latter 'Inaction' is the same situation as the case of injury-averting action. This means that remaining in a safe space is effective for injury mitigation.

Although there is no difference in dwelling environments between household structure, the injury rate of 'Single, Over 29' is significantly higher than 'Multifamily' (Fig. 14.21). The reason is believed to be due to the differences in lifestyle and family protection activity. These results mean risk control including not only dwellings but also lifestyle is required for detailed injury mitigation strategy for individuals. Here, lifestyle means indoor condition, family structure, and so on. Lifestyle and human behaviour naturally changes for each region and country. It also changed for day of week and time, even in the same household. In fact, of the more than 6,000 people killed by the 1995 Hyogoken Nanbu earthquake in Japan, most were in their bedrooms. That differs from our result as the injury rate is the highest in the kitchen. One of the differences between these earthquakes is the time of their occurrence. The Hyogoken Nanbu earthquake occurred at 05:46 and the Niigataken Chuetsu earthquake occurred at 17:56. In the future, the injury will be required to be differentiated between two time points, as during an earthquake and evacuation time, because these injury mechanisms are different from each other. It is not easy to adopt all of the above conditions; however, every problem is worth pursuing for the life-loss reduction strategy.

14.5 Conclusions

An extensive questionnaire survey on the various seismic effects for inhabitants, dwellings, and social settings was conducted in an area of Ojiya city affected by the 2004 Mid-Niigata earthquake. This survey is focused not only on damage to dwellings but also on injury details such as weapons, injury situations, human behaviour, and family structure. The results indicate that a total risk control strategy including lifestyle is required for the life-loss reduction strategy. This study and Okada et al. (2006)

are complementary. Therefore, we will compare this questionnaire dataset with the interview dataset by Okada et al. (2006). A continuous examination of this research would lead to the construction of a numerical estimation model for individual injury.

Acknowledgments We are indebted to Dr. Masahiro Sawada at Nagaoka Institute of Technology, the officers and inhabitants of Ojiya city for cooperation in collecting and recording data. We are also grateful to Dr. Nobuoto Nojima at Gifu University for environmental support.

Part IV
Exploring Approaches to Improving Casualty Modeling

Chapter 15
Advancements in Casualty Modelling Facilitated by the USGS Prompt Assessment of Global Earthquakes for Response (PAGER) System

D. Wald, K. Jaiswal, K. Marano, P. Earle, and T. Allen

Abstract The advent of the U.S. Geological Survey (USGS) Prompt Assessment of Global Earthquakes for Response (PAGER) system, in conjunction with several recent advances and trends in related data sources and research efforts, bring to light new opportunities within the overlapping realms of earthquake hazard, earthquake engineering, and earthquake epidemiological studies. While casualty modelling has admittedly often suffered from the lack of epidemiological rigour on the part of earth scientists and engineers, comparable laxity is also evident in some analyses of related hazard complexities on the part of social scientists. These limitations have often been due to insufficient oversight or interaction, or more commonly, insufficient data availability. Thanks to improved data sets, modelling approaches, and collaborations, there are now fewer obstacles to performing comprehensive casualty estimation, though formidable challenges remain. Under the auspices of the PAGER system, a global set of ShakeMaps has been produced for all significant earthquakes in the past 34 years (1973–2007). These event-specific ShakeMaps, constrained by any available data, are then combined with new global population data sets to develop systematic hazard and loss analyses. These and other important advancements, as well as their limitations, and their potential for contributing to casualty modelling are discussed. Example studies and applications are presented.

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15.1 Introduction

One of the primary correlatives for building damage, and thus casualties, is the site-specific shaking hazard. Rather than shaking intensity (whether characterised by macroseismic intensity, peak ground motion or response spectral values), magnitude has commonly been used as a proxy (e.g., Alexander 1996; Nichols and Beavers 2003; Eriksson 2006), oftentimes without consideration of earthquake source distance or event depth. Compounding these simplifications, often inconsistent tabulations of earthquake magnitude and fatalities as well as inaccurate source characteristics are used where more rigourous analyses of the hazard component of the problem are required. A potential remedy for these types of simplifications comes in the form of a systematic, openly-available, catalogue of historical earthquakes, including their associated parameters and casualties (here referred to as PAGER-CAT). An associated catalogue of ShakeMaps, developed primarily for the PAGER system, of all significant earthquakes over the past 34 years, and referred to as the ShakeMap Atlas complements PAGER-CAT by providing the systematic estimates of the spatial distribution of shaking for each event. The ShakeMap Atlas is online and is freely and openly available for researchers in several formats.

A second, but often under-utilised, correlative for casualties is the population exposure. Whilst seemingly obvious, this factor is also often overlooked while exploring explanatory variables. For example, the expectation that greater fatalities occur at night (the "time-of-day" factor) can only be proved (i) with specific examples of two events, which sample day and night, occurring in the same region, and having similar exposure levels as a function of intensity; or (ii) with statistical analyses of multiple events spread out over time in a particular region, but again, correcting for the relative exposure of the population to various shaking levels. By analogy, one cannot shed significant light on patterns of earthquake damage to structures without an independent indication of the shaking level and its variations with respect to mapped damage extents. Here too, help is on the way, primarily from the recent arrival of global population datasets (e.g. Landscan 2006; Bhaduri et al. 2002) which allow exposure levels to be computed (albeit, approximately) and considered as a normalising factor. In turn, the spatial distribution of global population, combined with the ShakeMap Atlas allows one to constrain – with varying levels of accuracy – both the local shaking intensity as well as the population exposed to that level of shaking. This combination is provided in PAGER's Exposure Catalog (EXPO-CAT), tabulated for each of the ShakeMap Atlas earthquakes.

One missing ingredient needed in formal analyses of earthquake losses is comprised of building-specific damage and casualty observations. Gradually, these data sets are being gathered, and critically, are being made publicly available (for example, see the Cambridge University Earthquake Damage Database, or CUEDD, see Chapter 5). A second ingredient for casualty modelling must come from social science contributions that help understand and thus constrain casualty outcomes. From cohort and other post-event interviews and evaluations, we can further constrain the numerous variables related to human response, an important component in casualty modelling that mitigate or increase casualties. These societally-dependent variables include personal protection actions, building egress rates, as well as rescue and emergency medical capabilities. In conjunction with the hazard ingredients mentioned above, there is hope for rapid advancement in the ability to estimate and understand these additional contributions of earthquake casualties on a global basis.

Initially, we discuss the data and contributions made under the efforts of the USGS PAGER system towards lowering some of the hurdles that limit casualty modelling. We then provide several example applications and demonstrate opportunities afforded by these new data sets and tools. Finally, we discuss caveats of the current approaches and other limitations that must be addressed to continue making progress, particularly as applied to rapid fatality estimation, which is at the core of the PAGER system.

15.2 PAGER'S Contributions to Loss Modelling

The PAGER system now plays a primary alerting role for global earthquake disasters as part of the U.S. Geological Survey's (USGS) response protocol. PAGER builds on ShakeMap, "Did You Feel It?" and other rapid earthquake information systems. Currently, PAGER automatically reports the number of people, and the names of cities exposed to severe shaking caused by an earthquake anywhere in the world, thus informing emergency responders, government agencies, and the media of a potential disaster within 20 min of the earthquake's occurrence. This information is available 24 × 7 via e-mail, text message, and the Internet.

In addition to near real-time applications, there are specific contributions developed under the auspices of PAGER that have broader benefits for the loss-modelling community. Near real-time information from PAGER, as well as all related applications, data sets, and tools, with corresponding online reference can be found at http://earthquake.usgs.gov/pager/ and http://earthquake.usgs.gov/pager/prodandref/index.php, respectively.

15.2.1 Hazard Contributions

Hazard-related products include: (i) databases on earthquake occurrence including event and casualty information, (ii) approximate VS30 soil site-condition maps for the world, (iii) an Atlas of approximately 5,600 ShakeMaps of significant global earthquakes over the past 34 years, and (iv) a catalogue estimating event-associated population exposures for each Atlas ShakeMap.

15.2.1.1 PAGER-CAT

A primary concern for hazard calculations is starting with the best composite earthquake catalogue of earthquake source parameters and loss data. Although unpublished, proprietary catalogues exist within the loss modelling community, we found no publicly available catalogue containing both comprehensive earthquake source parameters and fatality information. The necessary information is spread throughout numerous earthquake catalogues, reports, and online databases. Earthquake catalogues are created for different purposes, and consequently they excel in different areas. Some catalogues provide high-quality hypocentre information while others contain carefully researched damage and casualty reports.

This led us to develop a systematic approach to produce PAGER-CAT (Allen et al. 2009a), and to make it widely available. PAGER-CAT provides accurate earthquake source (e.g., hypocentre, magnitude, focal mechanism) information necessary to compute reliable ShakeMaps in the Atlas. It also contributes loss information (i.e., number of deaths and injuries) from historical events and characterises the deaths as due to shaking or other (secondary) causes. The first release of PAGER-CAT contains more than 140 fields specific to each earthquake, covering source and impact information and currently includes events from 1900 through December 2007 (with emphasis on earthquakes since 1973).

15.2.1.2 Global VS30 Server

In order to produce ShakeMaps nationally and globally, it was necessary to develop a procedure for deriving uniform shear-wave velocity (Vs30) estimates from data available on a global basis. Vs30, or the average shear velocity to 30 m depth, serves as a well-established proxy for ground motion site amplification and is used in building codes as well. To this end, Wald and Allen (2007) presented a method for deriving uniform global seismic site conditions from Shuttle Radar Topography Mission (SRTM) 30 arc second (approximately 1 km resolution) digital elevation data. More specifically, this method is based on simple correlations between measured Vs30 values and topographic gradient. Based on numerous requests for the Vs30 estimates for other hazard and loss analyses around the globe, we produced a Vs30 Online Server, allowing for online access and Vs30 grid file downloads for most of the globe.

15.2.1.3 ShakeMap Atlas

Utilising the PAGER-CAT and the global VS30 grid, and using the standardised ShakeMap approach of combining observations and ground motion estimates (Wald et al. 2005), we produced ShakeMaps for over 5,600 earthquakes which occurred from January 1973 through December 2007. Almost 540 of these maps were constrained in part by instrumental ground motions, macroseismic intensity data, community internet intensity observations, and published earthquake faulting rupture models. For each of the Atlas ShakeMaps, uncertainty maps are also provided. The uncertainty values (Wald et al. 2008b) can be used for computing uncertainties associated with the hazard component in loss modelling. In addition to its primary purpose – allowing for loss calibration – the Atlas is useful for earthquake planning, earthquake studies, loss modeling, and other hazard and risk analyses (for example, see UNISDR 2009).

15.2.1.4 Exposure-Cat (EXPO-CAT)

A catalogue of human exposures at each shaking intensity level was derived using current PAGER methodologies (e.g., Wald et al. 2008a). EXPO-CAT is derived from two key datasets: the PAGER-CAT earthquake catalogue (Allen et al. 2009a) and the Atlas of ShakeMaps (Allen et al. 2008). Exposure to discrete levels of shaking intensity is obtained by merging Atlas ShakeMaps with a global population database (LandScan 2006; Bhaduri et al. 2002) and hindcasting population with negative growth rates to estimate population exposure at the time of the earthquake. Combining this population exposure dataset with historical earthquake loss data provides a critical resource for calibrating loss methodologies against a systematically-derived set of ShakeMap hazard outputs. In addition, these population/exposure levels for all significant earthquakes in the past 34 years allow comprehensive statistical analyses to be made that account for relative exposure within events and among events for correlation with other factors (for example, see "time-of-day" correction, below).

15.2.2 Loss and Risk Contributions

On the impact assessment front, PAGER-related studies and tools include extensive databases on: (i) country-based global building inventories (developed in collaboration with the Earthquake Engineering Research Institute's World Housing Encyclopedia project, WHE), and (ii) empirical, semi-empirical and analytical fatality and building damage functions. The global building inventory is discussed in detail in Jaiswal and Wald (2008); the three PAGER loss models are described in Jaiswal et al. (2009b), Porter et al. (2008), and Wald et al. (2008a).

PAGER's use of multiple fatality loss models (Wald et al. 2008a, b, c), stems from the wide, global variability in the built environment and uncertainty associated with inventory and structural vulnerability data, as well as the knowledge about past casualties in different countries. The empirical model relies on country-specific earthquake loss data from past earthquakes and makes use of calibrated casualty rates for future prediction. The semi-empirical and analytical models are engineering-based models that rely on knowledge of complex datasets including building inventories, time-dependent population distributions within specific building types, the vulnerability of regional building stocks, and casualty rates given structural collapse. The semi-empirical model uses expert judgment to define the probability of collapse as a function of shaking intensity, whereas the structural vulnerability functions adopted in the analytical model are derived using the HAZUS capacity-spectrum method and thus require spectral acceleration as the hazard input. Both the semi-empirical and analytical approaches rely heavily on published or reported casualty rates, and thus it is of the utmost importance to the PAGER system to further refine building collapse and related fatality rate functions.

For the purposes of this discussion, we note that the PAGER empirical model can be derived directly from the data sets described above. In that sense, best-fit parameters can be obtained to best hind-cast fatalities from past events (Jaiswal et al. 2009a). However, both the semi-empirical and analytical model approaches require forward calculations which contain interdependent variables that can only be constrained by improved data on time-dependent building occupancy patterns, spatial building distribution, building collapse functions, and lethality ratios as well as social aspects, primarily on human response (e.g., building egress) and emergency and medical response (post-collapse mortality). Since separating these variables in the fatality estimates is extremely difficult in terms of an inverse problem, particularly with severely limited data constraints, improvements in the semi-empirical and analytical loss models will come only as separate event-specific loss computations are performed to better constrain these important variables.

PAGER efforts now focus primarily on further refining each of three separate loss methodologies and from them, producing alerts with fatality estimates (as well as uncertainties) for the wide variety of global risk environments. Currently, both the empirical and semi-empirical models are complete and are allowing USGS to produce global fatality estimates in near real-time. These data, tools, and models are valuable for other engineering and seismological studies and are also open and freely available. In addition to the primary audience of response users, beneficiaries from PAGER's open-access environment include, for example, loss-modellers (global VS30, ShakeMaps, inventories, vulnerabilities), reinsurers (catastrophe bonds), and non-governmental agencies (risk analyses).

15.3 Example Applications

The PAGER data sets are contributing to PAGER-related as well as parallel hazard and loss modeling analyses. For example, Trendafiloski et al. (2009b), take advantage of the Global Vs30 server for comparing losses computed for large cities based on varying spatial scales for hazard, site condition, and building inventories. These efforts contribute to developing QLARM, a rapid, global loss estimation project. Similarly, CUEDD points to the ShakeMap Atlas to provide shaking intensity estimates for each earthquake and at each location for which they provide detailed accounting of building losses. Below we provide two sample studies recently completed which also were made possible with these new data sets.

15.3.1 Geospatial Analysis of Casualties due to Secondary Hazards

One example of the utility of PAGER-CAT is shown in Fig. 15.1, where Marano et al. (2009) separate out secondary causes of fatalities for earthquakes over the past 34 years. This work was pursued to answer questions about how and, critically, where to prioritise research and modelling efforts to augment PAGER's capability

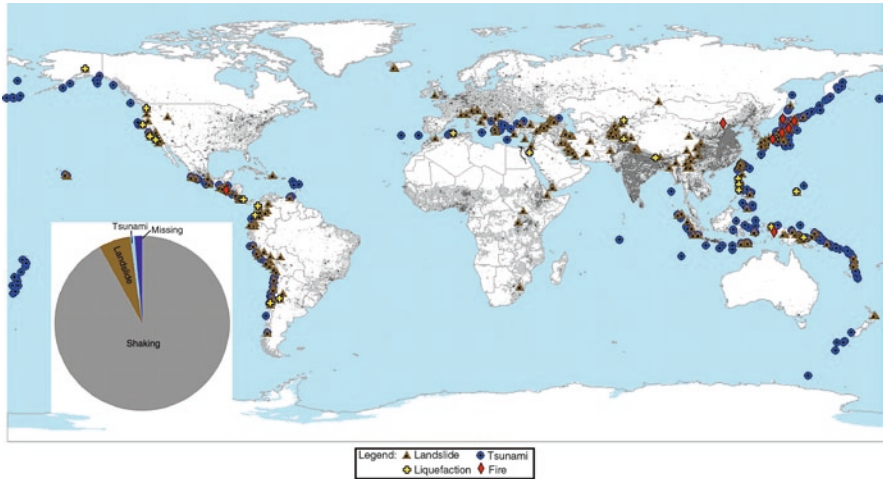

Fig. 15.1 Epicentres of earthquake-induced landslide, liquefaction, tsunamis and fire. *Inset* shows fatality causes for all deadly earthquakes between September 1968 and June 2008, which is dominated by shaking-related deaths (From Marano et al. 2009; see that manuscript for details)

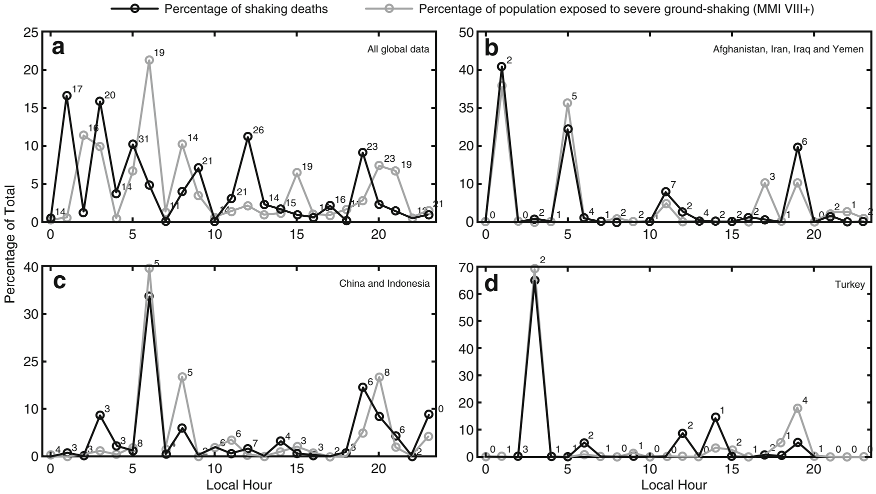

Fig. 15.2 Percentage of shaking deaths to have occurred at each local hour, in addition to the estimated percentage of people exposed to MMI VIII or higher for; (**a**) all global earthquakes since 1973 with shaking fatalities; (**b**) the Middle East (Afghanistan, Iran, Iraq, and Yemen); (**c**) Eastern Asia (China and Indonesia) and; (**d**) Turkey. Numbers to the *top-right* of data points represent the number of events in that hour window (From Allen et al. 2009b; see that manuscript for details)

to estimate shaking-related deaths. As shown in Fig. 15.2, Marano et al.'s analyses show that landslide hazards require the most attention (not counting the unique 2004 Sumatra tsunami disaster), and that each of the secondary hazards has particular and perhaps predictable geospatial concentrations around the globe. While tsunamis obviously require near-oceanic earthquake sources, landslides are a significant contributor to fatalities in predictable, high-slope areas of the globe. Similarly, post-secondary fires are a major concern for casualties, primarily in Japan and the United States.

15.3.2 Time-of-Day Corrections for Casualties

As an example use of EXPO-CAT, Allen et al. (2009b) compared shaking-related deaths since 1973 at different times of day to examine the "time-of-day" effect on earthquake casualties. Essentially, a significant signal was expected (e.g., Scawthorn et al. 1978; Coburn and Spence 2002) given the combined potential factors that would contribute to higher fatalities at night: for example, higher percent of the population in vulnerable structures, fewer people escaping collapsed buildings, and community and emergency response (including lack of lighting due to power loss). However, once corrected for earthquake occurrence- more specifically, the population exposed to intensity VIII and higher- Allen et al. found little quantitative evidence to suggest that time-of-day is a consistent, significant factor in earthquake mortality (see Fig. 15.2). Moreover, earthquake mortality appears to be more systematically linked to the population exposed to severe ground shaking (MMI VIII+), an observation made possible only with the EXPO-CAT database.

One can imagine a number of analogous studies that could be made with these data sets. For example, structural damage as a function of building type can be examined for a particular earthquake using a ShakeMap, population, and building inventory databases publicly available via the USGS PAGER website. However, without a reasonable map of the shaking distribution, little can be quantified in terms of relative vulnerability; again, as with the time-of-day analysis, the actual or estimated exposure to different shaking levels must be taken into account.

15.4 Limitations and Ongoing Needs

All of the data sets described above have inherent as well as resource-related limitations that result in inaccuracies. PAGER-CAT source parameters are derived quantities; some earthquakes were better recorded than others, and they have differing data vintages. ShakeMaps constituting the Atlas are a combination of shaking recordings, macroseismic observations, and shaking estimates; each of these carries a wide range of uncertainties depending on region- and event-specific circumstances (e.g. Wald et al. 2008a). Likewise, once a ShakeMap of intensity distribution is produced, EXPO-CAT, made by combining the spatial intensity and population distributions, carries new uncertainties, in that the population itself is approximate (Bhaduri et al. 2002) and we further correct for the change in population over time, as far back as 1973. In some cases this may not be too bad, but one can imagine regions where country-wide growth curves do not adequately capture essential migration and inconsistent growth patterns. Lastly, while the definition of an earthquake-related death is less ambiguous but not completely unambiguous, the numbers associated with "injured" in the PAGER-CAT database are poorly established for most events. While in some cases this is quite understandable given the disaster at hand, more recent collections show the importance of high resolution and quality casualty data sets (e.g. Peek-Asa et al. 2005). Significant efforts are needed in this domain.

These uncertainties can, in part, be reduced with more careful analyses at finer temporal and spatial scales, and with more data for individual events. It is hoped by the PAGER team that any deficient or erroneous aspects of any of the catalogues be brought to light with heavy use of these data sets. As with open-source software, our open data policy will undoubtedly allow more experts from individual countries to examine our data and sources. We anticipate updating these data sets as new, additional, or improved data or models come to light. For example, we will be regenerating the entire PAGER-CAT data set in the near future to incorporate the latest ground motion prediction equations (e.g., Stewart et al. 2008). After evaluation, for example by Allen and Wald (2009), a new suite of ground motion prediction equations will be employed to recompute the entire ShakeMap Atlas. These revised intensities, in turn, require regeneration of exposures for EXPO-CAT. We hope that with country-wide earthquake data assemblages, individual or event-specific errors will tend to be minimal in, for example, the PAGER empirical loss model coefficients. However, reduced uncertainties and the best possible hazard models are of upmost importance for the PAGER system, so this process will continue. In addition, we will provide routine bi-annual updates with recent earthquake data.

15.5 Discussion and Conclusions

Proper casualty loss estimation requires assignment or knowledge of a number of interdependent variables. A number of recent contributions towards the improvement of casualty modelling have been discussed herein, in particular, those related to the developing the PAGER project and with emphasis on the hazard component. Reducing the uncertainties associated with these variables is extremely important: for example, Peek-Asa et al. (2003) show the importance of rigorous incorporation of the variations in the shaking hazard when drawing conclusions about factors controlling casualties. For the 1994 Northridge, California earthquake, direct comparison of shaking levels derived from ShakeMap allowed Peek-Asa et al. to make credible conclusions concerning causal relations between casualties and ground motion levels, building damage, and inhabitants' locations. Of course, while the data for that event were highly detailed, the total number of fatalities was low, so these conclusions cannot be applied to more lethal areas of the globe.

Fortunately, significant data sets, particularly suitable for comparing hazard and losses directly, have also been acquired for other recent earthquakes (e.g. CUEDD).

Important studies of the 1995 Kobe, Japan, the 1999 Kocaeli, Turkey, and Chi-Chi, Taiwan, events also provide loss data for events with well-constrained ground motions from seismic recordings. There is hope that future release of strong motion and casualty data from the 2008 Sichuan, China, earthquake will contribute improved models of that event for a country that has dominated earthquake fatalities historically.

These, and many other earthquake studies, point to the potential to help constrain, for a range of varying built environments, time-dependent building occupancy, spatial building distribution, building collapse functions, injury distributions, and lethality ratios as well as social aspects, primarily on human response (e.g. building egress) and emergency response (post-collapse mortality). Yet, data sets to constrain many of these predictor variables are poorly constrained for most of the globe.

Only by either gathering and by making openly available additional and better data in other parts of the world, or making improved estimates of the hazards (e.g. the ShakeMap Atlas), can we continue to expand the databases by which better fatality estimates can be made. The primary function of the ShakeMap Atlas and EXPO-CAT is to supplement and extend these event-specific loss studies, albeit to a lesser degree of accuracy, to many more events, and for many areas of the world, where fewer hazard and loss data are available. Done systematically, we hope this extrapolation will prove useful for applying loss models on a global scale.

Chapter 16
Challenges in Collating Earthquake Casualty Field Data

E.K.M. So

Abstract Understanding why and how injuries and deaths are caused in earthquakes is essential for mitigating and preparing for future human losses. It is only by exploring these causal pathways that engineers, architects and all related in the field of earthquake protection can strive to prioritise and offer feasible strategies to reduce future casualties. The best way to gain a holistic view of causes of injuries, capturing information of a survivor's experiences leading to different severities and types of injuries, is by surveying the survivors of an earthquake in target sample groups. However, there are very few events in the past where in-depth surveys exploring the causes of deaths and injuries of survivors have been conducted. This is because collecting representative samples is not straightforward and there is currently no standard procedure or sufficient funding in this research area to ensure data is collected after each event. This paper starts by highlighting the difficulties in acquiring data from the field after an earthquake and providing suggestions for overcoming some of the problems with a questionnaire specifically designed to explore all areas of survivors' experiences from the moment of earthquake occurrence to their current situation. The robustness of the design is tested in three real events and modifications to the original design and reasons behind these changes are explained. The aim of this paper is to highlight the importance of casualty data collection after real events and to begin the process of standardising and achieving a global questionnaire form for the future.

16.1 Introduction

There are a number of unique challenges associated with collecting information from the field after an earthquake. No earthquake is the same. They are unpredictable and large earthquakes can cause major damage both physical and social, during and after the event. Each event's unique characteristics add to the complexity in

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defining and classifying earthquake-related casualties and in obtaining reliable data that influences morbidity and mortality.

The damage to building stock and injuries to its inhabitants can greatly vary depending on its foundations, the underlying soil condition and local surroundings. The differences in building construction quality and therefore vulnerability to earthquakes of the same building types also vary greatly across countries. For example, although a reinforced concrete house may provide life safety in New Zealand, the same may not be true in developing countries, where building control is not as stringent (Petal 2004). The same occupant's response during an earthquake may be protective against injury in one event but be a risk factor in another. Exiting a vulnerable building founded on flat ground is likely to save lives, but on slopes prone to landslips, the benefit may prove to be minimal as shown in the Kashmir earthquake of 2005.

One of the central problems with casualty modelling is the lack of good quality data on past events. Unlike engineering damage surveys, where damage states classifications have been developed for some years and are uniformly used, there has been no standard methodology used in the collection of injury data from earthquakes in the past. "For the past 25 years researchers in the casualty estimation field have called for interdisciplinary, standardized data collection framework for the development of a standardized classification scheme for all aspects of earthquake-related casualties, including such varied items as injury mechanism and building damage." (Shoaf 2002). In their review of 150 articles predominantly about casualties or casualty estimation, Shoaf et al. (2000) found very few scientifically valid designs and procedures for casualty data collection. Finding no standard injury classification system, the authors proposed a classification scheme that could be useful to both public health and engineering.

Early data collection about a little-understood phenomenon is necessarily descriptive. Some studies have simply been demand-focused, in other words, case series describing people presenting themselves for medical treatment. These are mostly of use to health practitioners. However, as patterns begin to emerge and hypotheses can be formulated about the causes of casualties, the studies then can become more analytic, or case-controlled, looking at a range of variables. There are a number of methodological parameters that can be varied: population selected, sources of data, data collection methods, and data analysis methods.

When earthquakes have a relatively small impact, it makes perfect sense to do a complete census of deaths, and in some cases, hospitalised injuries. Here the data may be collected from coroners' reports, hospital admission records, and hospital emergency room or treatment records. Under overwhelming conditions of a mass casualty event however, medical record keeping is likely to be sparse. Logs may not exist or may be incomplete. Major problems are encountered in sifting through the medical records of earthquake-related injuries from other causes. Relying on subjective assessments of whether an injury was likely to be directly or indirectly related to the earthquake, or relying solely on baseline data from other time periods, means imperfect results. The other major problem is that medical records simply do not contain the answers to many of the important questions we have, such as

"Where was the subject at the time of earthquake?" "What was he/she doing?" and "What kind of object hit the subject?"

As the total number of casualties increases a full population sample becomes impossible to obtain, and some form of sampling must take place. Surveys need to be accomplished either face-to-face, by telephone, or by post. Reconnaissance studies in the past have used multiple inputs such as expert informants, field data collection from hospitals, and limited population surveys to acquire data. Although not rigorously scientific, these studies have still been informative and important.

An innovative use of the cohort approach was in Armenia to follow seven thousand employees of the Ministry of Health (Armenian et al., 1992). This has yielded valuable results and provided an opportunity to measure long-term health impacts. Where population sampling becomes necessary, a geographically or spatially-stratified random sample is an important starting place in order to control for the differential spatial impact of the earthquake itself. The inclusion of a control group, whose demographics can be compared to the whole population to detect selection or sampling bias, is clearly desirable.

Case-controlled studies surveying injured and uninjured controls have been undertaken in order to assess the relative risk for physical injury associated with different environments, different socio-demographics, and the absolute risk associated with a particular earthquake in a particular environment. "A case-control study is ideal for identifying risk factors for rare outcomes in a defined population (Shoaf and Peek-Asa, 2000)." A population count of all cases is compared with controls that are a representative sample of the base population. Odds ratios are calculated for risk factors using logistic regression. In a case-control study of the Loma Prieta earthquake, for example, the case group included those killed, those seen at a hospital or flown out for treatment, and for comparison, a random-digit-dial telephone survey was conducted with residents of the area. The sample was divided into non-injured and injured controls. Visits were later made to more than 500 sites in a 10-day period, where engineers assessed structure-related risks to compare them to residents' own assessments of damage (Jones et al., 1993). As Shoaf and Peek-Asa explain, although the measure sought is the outcome odds ratio (of being severely injured), in fact, it is the exposure-odds ratio that is being measured. This is the statistic most often calculated for comparison in case-controlled studies, that is, the odds of injury in exposed individuals to the odds of injury in the unexposed.

However, it is sometimes difficult to obtain an appropriate control group for case-control studies. Estimating the population in an area at the time of the earthquake can also be complicated as in many developing countries quality census data may not be available and the demographics of the population may not be known. Even if there are good census data, people commuting in or out of an area can greatly affect the population at risk. The affected population, and most probably those who have been affected the most, tend to migrate out of the devastated areas. This migration could bias results in case-control studies, especially since those that choose to move may be the ones whose houses were damaged the most or suffered most in terms of injuries. Consequently, most post–earthquake studies are descriptive and utilise a convenience-based sample, i.e. a selection of people from accessible villages or easy to attain are used rather than a completely random group.

In order to overcome this bias and other noted difficulties, an attempt has been made to create a universal questionnaire survey to capture the multidisciplinary nature of earthquake epidemiology and record the experiences of the victims and survivors of particular events, rather than relying solely on published information and piecemeal information from other disciplines.

Funding and collaborative opportunities were sought by the author and the survey was used to capture experiences of survivors of earthquakes in three recent events. These were the Kashmir earthquake of October 2005, the Yogyakarta earthquake of July 2006 and the Pisco earthquake of August 2007. By using the same method of collection for different earthquakes, cross-event analysis can be carried out enabling trends and hypotheses to be developed and tested. This will be an important step to a better understanding of earthquake epidemiology, improving existing casualty estimation and the formulation of global casualty rates.

16.2 The Questionnaire

16.2.1 Fundamentals of Design

The thinking behind the design of the questionnaire is simple; it needed to capture what happened to survivors of an earthquake from the moment the earthquake occurred to where they are at the time of the interviews and encapsulate the factors contributing to their survival. The key relationship explored is the causal pathway of injuries and deaths.

There have been surveys developed in the past which have examined casualties from earthquakes. For example, the Japanese questionnaires have been successful in capturing data from their national events through postal surveying techniques (Koyama and Ohta 2007) and also internationally by interviews; however the latter have been focused on deriving micro-intensity levels and on hospital capacities, not on causes of injuries and deaths (Murakami and Ohta 2004; Kuwata 2004).

Two surveys in particular have been used as a reference for the Cambridge design, namely the Choudhury and Jones (1996) survey, though this was never used to capture any real-time data from an actual event, and the Gölcük survey form (Petal 2004). Dr Marla Petal's survey was on a random sample of the community of Gölcük after the Kocaeli earthquake of 1999.

In reviewing these two pieces of work, the main aim was to learn from their format and questioning and also from the results that were generated, and applying these lessons to the Cambridge design.

The original data collection form developed by experts involved in disaster epidemiology at the John Hopkins Workshop[1] was divided into four parts consisting of a master data form, an on-site form, one to capture hospital data and a few questions on buildings in the area. The master data form enquires about the disaster event, including questions on early warnings and transportation disruption. The form was intended to capture information on all disasters, not only earthquakes. The on-site form has four parts and poses questions on injuries, search and rescue, locations of injured people within buildings and the deceased. It is assumed these forms are designed for use in interviews with personnel from various fields. These include search and rescue teams and medical personnel as there are questions on extrication conditions and where deceased people are found in buildings.

The last two parts of the form are summaries of information on deaths and injuries from individual hospitals and also information on affected buildings. However, it is unclear whether these are to be completed separately or whether the injuries for each extricated person should be related back to the buildings housing the victim. Due to the strain medical staff is under, records may not be kept from which to extract these medical data.

The Choudhury form progresses from qualitative questioning to a coded format and contains a similar set of questions as the original John Hopkins design. However, it is clear from the level of detail on these forms that they cannot be answered by a single group. In order for each questionnaire to be completed, a host of people, from occupants, to search and rescue teams and medical personnel associated with a specific building must be interviewed. This could be one of the reasons why this document was never advanced further.

In their paper, Choudhury and Jones (1996) show an example of a completed building part of the form for one single facility after the 1971 San Fernando earthquake in California. Accompanied with photographs as shown in Fig. 16.1, this was clearly taken from damage surveys. Unfortunately there was no information available to relate structural damage to injuries, which was the aim of the paper as stated in the abstract: “to consider both casualties and building damage jointly”.

Although clearly intended for completion by search and rescue teams and others in the relief phase, there are several interesting questions posed in the original draft and this later version of the form which have been adopted in the Cambridge design, especially the questions on access and the elapsed time to extrication and medical treatment. The Choudhury form gives an insight into key questions in earthquake epidemiology and offers a sensible sequence of questioning. The intention of the Cambridge design is to create a questionnaire which marries this line of questioning with key components used to derive earthquake casualty estimates.

Petal’s survey heavily influenced the way the questions in the Cambridge questionnaire were set up, since apart from the injuries and causes of injuries, this form also

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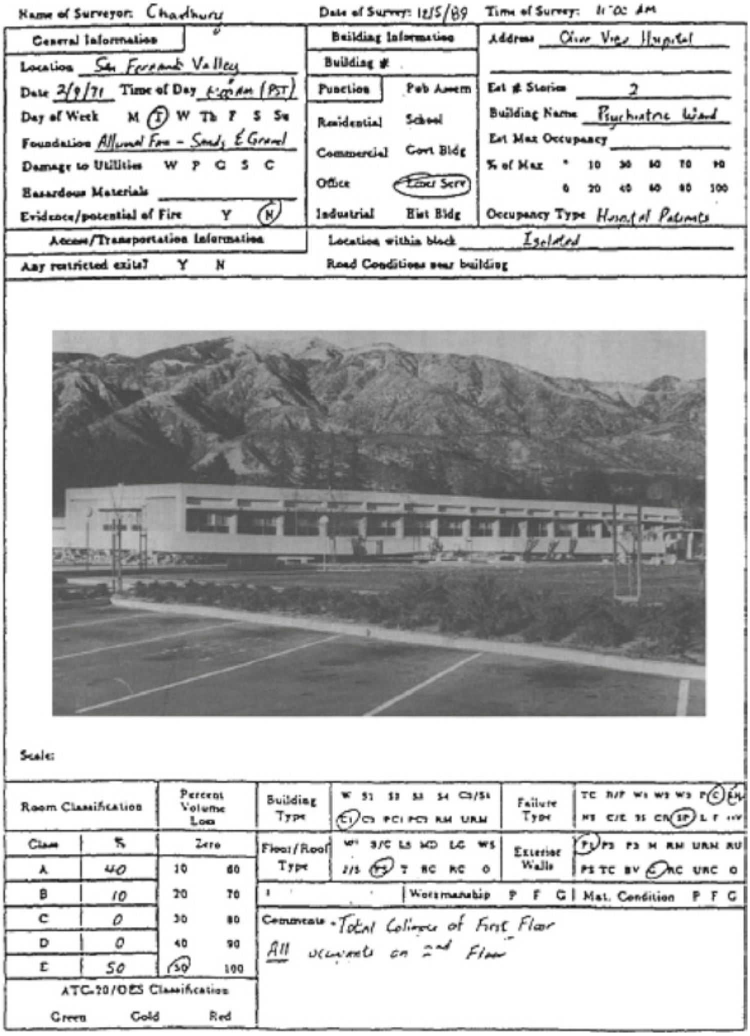
[1] This was the International Workshop on Earthquake Injury Epidemiology for Mitigation and Response at The John Hopkins University in 1989. This was the first and unfortunately last gathering of a group of international leaders in the field of earthquake injury epidemiology including Alexander, Armenian, Coburn, Coulson, Jones, Krimgold, Noji, Scawthorn and Shiono.



Name of Surveyor: Chadhury   Date of Survey: 12/5/89   Time of Survey: 11:00 AM

General Information

Location San Fernando Valley
Date 2/9/71 Time of Day 6:00 AM (PST)
Day of Week M [✓ T] W Th F S Su
Foundation Alluvial Fan - Sands & Gravel
Damage to Utilities W P G S C
Hazardous Materials
Evidence/potential of Fire Y [✓ N]

Building Information

Building #

Function
Residential Pub Assem
Commercial School
Office Govt Bldg
Industrial [✓ Emer Serv]
Hist Bldg

Address Olive View Hospital
Est # Stories 2
Building Name Psychiatric Ward
Est Max Occupancy
% of Max 0 10 20 30 40 50 60 70 80 90 100
Occupancy Type Hospital Patients

Access/Transportation Information

Any restricted exits? Y N
Location within block Isolated
Road Conditions near building

Scale:

Room Classification		Percent Volume Loss		Building Type	W S1 S2 S3 S4 C3/S5 [✓ C1] C2 PC1 PC2 RM URM	Failure Type	TC N/F W1 W2 W3 P [✓ C] EH HS C/E SS CN [✓ SP] L F ...
Class	%	Zero		Floor/Roof Type	W1 S/C LS MD LG WS 2/S [✓ FS] T RC RC O	Exterior Walls	[✓ P1] P2 P3 M RM URM RU PS TC BV [✓ C] RC URC O
A	40	10	60		Workmanship P F G	Mat. Condition P F G
B	10	20	70	Comments - Total Collapse of First Floor All occupants on 2nd Floor		
C	0	30	80			
D	0	40	90			
E	50	[✓ 50]	100			

ATC-20/OES Classification
Green Gold Red

Fig. 16.1 The building element of the Choudhury and Jones (1996) survey

captures the sequence of behaviour and decisions made leading to the respondents' survival. In addition to questions on injuries there is a focus on causes of injuries and more importantly on non-structural causes. Although the Choudhury form had questioned the cause of injuries and deaths during the earthquake, there are many instances where injuries are caused after an earthquake's main shock or are combinations of different factors. These are captured in Petal's questionnaire. The use of field choices also makes post-processing easier as all available options will be coded with the exceptions of 'others'. Analysing answers from the Choudhury form may have been extremely time-consuming and prone to data-entry errors.

There are, however, certain aspects of Petal's survey which were added and improved on. First and foremost, Petal's form was a 27-page questionnaire which is evidently too long for on-site interviews. For her survey, the focus was on gaining awareness of what happened to survivors in a community and subsequently to involve the community in mitigation and preparedness campaigns. There was therefore a long period of engagement with the community leaders and her team of interviewers were based in the community and had the luxury of time (both in terms of length of interviews and time in the field), which may not be the case in other events. In addition, the format of the questionnaire, in which the form is used for the entire household of up to ten individuals, was considered cumbersome; to eliminate mistakes on entry of data, this was not repeated. A comparison of a page of questions in Petal's survey and in the Cambridge design is shown in Fig. 16.2. Even though interviewers would be familiar with the questions, it is important to keep questions and options concise and clear.

The Cambridge questionnaire takes into account the different aspects of these previous pieces of work but also includes questions beyond the initial cause of injuries to explore the search and rescue efforts and to develop understanding of treatment delays and infrastructure capabilities. The design of the survey form was centred on the following research questions:

- What happens to people in earthquakes?
- How were they injured?
- Why did they survive?
- How did others die?
- What are the causal factors to complications of injuries?
- Are there contributing factors to survival applicable in the global arena?

Drafts of this questionnaire were shown to a variety of people from different agencies involved in disaster management from World Health Organisation (WHO) and HANDICAP representatives in Indonesia and Pakistan to academics in Japan and America (Yamaguchi University and UCLA) who are involved in casualty research, and their feedback and comments have been incorporated into the final design. What is clear is that there has not previously been this kind of investigation into survivors of earthquakes, exploring the potential and extent of contributing factors to survival; this piece of work was therefore welcomed by the review panel.

16.2.2 Design of the Questions

The focus of this questionnaire is to derive correlation relationships to better understand the process that leads to injuries and deaths. It was anticipated that in interviewing survivors of an earthquake they could provide data on:

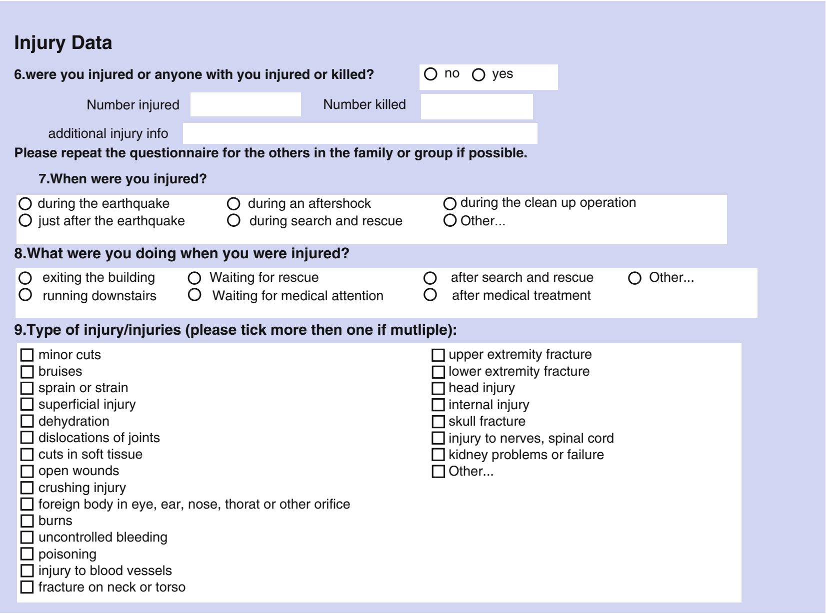
1. The physical location of the survivor (whether inside a building or outside)
2. Aspects of human behaviour in response to the earthquake (fear levels, immediate reaction, what was felt)
3. Physical damage to structures
4. Causes of death and the nature and extent of injury to survivors (themselves and others with them)
5. Knowledge of earthquakes and what to do in them

I am going to ask the same set of questions for the people who were with you at the time of the earthquake.

26. Was anybody in your household injured or killed as a result of the earthquake? 26.__________
YES.. 1
NO... 2 *(skip to 27)*

Please answer the following questions from the oldest to the youngest person who was injured or killed

	PEOPLE IN HOUSEHOLD DURING EARTHQUAKE									
	1	2	3	4	5	6	7	8	9	10
26a,Names	26a.1	26a.2	26a.3	26a.4	26a.5	26a.6	26a.7	26a.8	26a.9	26a.10
26b,Was he/she injured or killed?	26b.1_ _	26b.2_ _	26b.3_ _	26b.4_ _	26b.5_ _	26b.6_ _	26b.7_ _	26b.8_ _	26b.9_ _	26b.10_
INJURED	1	1	1	1	1	1	1	1	1	1
KILLED	2	2	2	2	2	2	2	2	2	2
26bx,Did he/she have any disabilities or mental problems due to the earthquake?	26bx.1 _ _	26bx.2 _ _	26bx.3 _ _	26bx.4 _ _	26bx.5_ _	26bx.6_ _	26bx.7 _ _	26bx.8 _ _	26bx.9_ _	26bx.10 _ _
DISABILITY	1	1	1	1	1	1	1	1	1	1
MENTAL PROBLEM	2	2	2	2	2	2	2	2	2	2
NO PROBLEM	3	3	3	3	3	3	3	3	3	3
26c..when was he/she injured / killed?	26c.1– –	26c.2– –	26c.3 – –	26c.4– –	26c.5 – –	26c.6 – –	26c.7– –	26c.8 – –	26c.9 _ _	26c.10 – –
DURING THE EARTHQUAKE....	1	1	1	1	1	1	1	1	1	1
JUST AFTER THE EARTHQUAKE.	2	2	2	2	2	2	2	2	2	2
DURING AN AFTERSHOCK.	3	3	3	3	3	3	3	3	3	3
DURING SEARCH AND RESCUE.	4	4	4	4	4	4	4	4	4	4
DURING CLEAN UP.	5	5	5	5	5	5	5	5	5	5
OTHER(SPECIFY)_ _ _ _ _ _ .	6	6	6	6	6	6	6	6	6	6



Injury Data

6.were you injured or anyone with you injured or killed? ○ no ○ yes

Number injured Number killed

additional injury info

Please repeat the questionnaire for the others in the family or group if possible.

7.When were you injured?

○ during the earthquake
○ just after the earthquake
○ during an aftershock
○ during search and rescue
○ during the clean up operation
○ Other...

8.What were you doing when you were injured?

○ exiting the building
○ running downstairs
○ Waiting for rescue
○ Waiting for medical attention
○ after search and rescue
○ after medical treatment
○ Other...

9.Type of injury/injuries (please tick more then one if mutliple):

☐ minor cuts
☐ bruises
☐ sprain or strain
☐ superficial injury
☐ dehydration
☐ dislocations of joints
☐ cuts in soft tissue
☐ open wounds
☐ crushing injury
☐ foreign body in eye, ear, nose, thorat or other orifice
☐ burns
☐ uncontrolled bleeding
☐ poisoning
☐ injury to blood vessels
☐ fracture on neck or torso
☐ upper extremity fracture
☐ lower extremity fracture
☐ head injury
☐ internal injury
☐ skull fracture
☐ injury to nerves, spinal cord
☐ kidney problems or failure
☐ Other...

Fig. 16.2 Comparison of Petal’s survey format (*top*) and the Cambridge design (*bottom*)

6. Search and rescue efforts, whether they were trapped or not
7. Treatment of injuries
8. Infrastructure and communication disruption
9. Where they are now (at the time of the interviews) and their hopes and concerns for the future

The design of the questionnaire was carefully thought out to record the chronology of a survivor's history. In order to capture the sequence of events, each element of the survey follows a logical order but was also designed to help interviewees recount the process, without intruding too much into their emotional state. With this in mind, advice was sought from Dr Stephen Platt, an anthropologist at Nottingham University and also from Dr Anne Cockroft, a Consultant and Senior Lecturer in Occupational Health Medicine, also a director of CIET (http://www.ciet.org/en/) with expertise in carrying out community based surveys in countries all over the world, especially Pakistan. For medical advice, the design was reviewed by Dr Peter Baxter, a consultant physician in occupational and environmental medicine with interests in the effects of natural disasters at the School of Clinical Medicine at the University of Cambridge and Mr John Beavis, Orthopaedic Surgeon who has worked in the North West Frontier Province of Pakistan providing training for primary trauma care since 2003.

16.2.3 Challenges in Designing the Questionnaire

The proposed interviews require the participants to give testimonies reviving traumatic moments of their lives. Therefore, in designing the questionnaire, a carefully thought out sequence of closed and open questions was included to form a structured interview. The interview starts with simple questions on personal details, which are quick to answer and allows the respondent time to get used to the interviewing process and the interviewer. The more difficult set of questions follow but these are deliberately placed in chronological order and are all closed questions, requiring one-worded replies. The questionnaire survey ends deliberately with simple questions on communication disruption which are again very quick to answer and distract the respondents from the strain of the middle section. Lastly, it was considered important to finish the interview on a *positive note* with questions on their hopes for the future and on recovery. These are the only open questions of the survey and are deliberate to help respondents 'unload' their thoughts without reference to the pain of the day and weeks following the event.

In all of these surveys, the interviewers were local to the affected area and no interpreters were used. They were all welcomed into the homes of the respondents as listeners and had the support of the others in the team throughout the surveying period.

It was also a challenge to ensure that no bias was introduced by the actual design of the questionnaire and in the way questions are laid out. The questions have to guide the interview but not lead respondents to answers. For example, there is always a danger when providing options to questions that the interviewees may subconsciously answer with one of the provided options. There is no way of controlling this with a mail survey but for personal interviews, it is possible to reduce this bias by asking the interviewers to simply ask the question. Unless the respondent does not understand the question and needs prompting with examples, the interviewer would then simply see whether the answer matches an option and fills that in. If there is no match found, the interviewer would fill in the provided answer in the other column.

In designing the layout of the questionnaire, careful consideration was placed on making the questionnaire concise and including diagrams to document actual locations of injuries as well as giving responders a diagrammatic illustration of what is meant by different damage states. Figure 16.3 shows the diagrams used in the questionnaire forms.

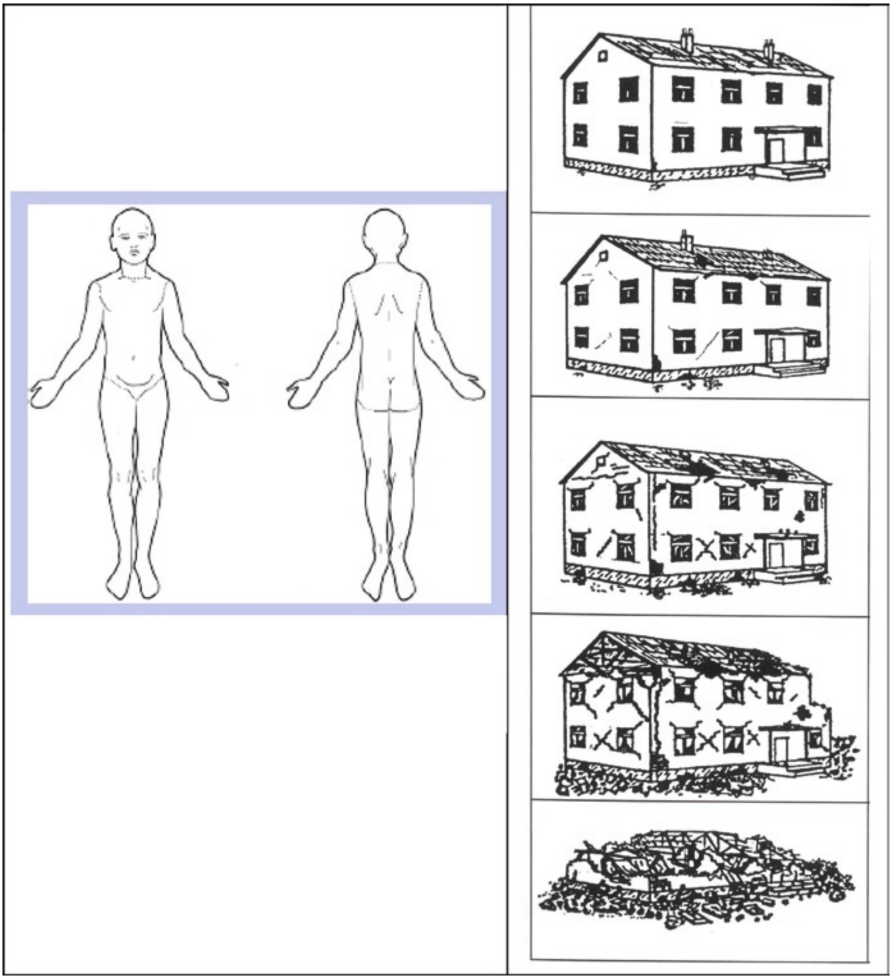


Fig. 16.3 Diagrams used in the questionnaire to mark on injury locations and to explain differences in damage states

The final form is appended to the end of this chapter. In particular, the focus is on recording whether the respondent was injured and what type of injury was sustained. It is just as important to capture the experiences of those unharmed by the event and why. The types of injuries listed in the Cambridge design were critically reviewed by the two medical consultants to make sure that the descriptions are accurate and reflect true trauma and earthquake-related injuries. These are positioned in increasing order of severity starting with minor cuts and bruises to the most severe internal organ failures. The diagrams of the front and back of a body (shown in Fig. 16.3) are an important part of this section. Rather than capturing this information in the form of a table as in the Petal survey, it was felt that the answers would be recorded more accurately if respondents were able to mark their specific injuries on the related part of the body. This information could also be useful if future analysis required AIS injury severity scoring. In later versions of the questionnaire, an extra question on the severity of injuries was added.

16.2.3.1 Injury Coding

Injury-coding is an important aspect of epidemiology. Noji et al. (1989) argue for the broad importance of a quantitative injury characterisation that can be calculated for an individual at specific points in time. This might be used in anticipating the injury-severity case mix associated with a particular collapse and planning medical response. Coding would be useful for triage in order to prioritise transportation and treatment, to evaluate the efficacy of search and rescue and on-site medical care. By coding injuries it is possible to see if there is a relationship between mortality and morbidity and time elapsed between critical interventions (extrication, first aid, transportation, treatment) (Noji et al. 1989). This type of coding requires the experience of well-trained “first aiders” or other professional emergency responders pressed into combining emergency response with epidemiological data collection, which in reality will be difficult to implement.

In general, coding can be considered physiological or anatomical. Since physiological approaches assess the body’s response rather than the injury itself, they can be used more rapidly and adapted for lay responders in the field. Anatomical measures require medical assessment of body parts and amount of damage and do not work well until after treatment or autopsy. Noji (1990a, b) argues that since some retrospective evaluation may depend on the survey of survivors by lay interviewers, while others may be made by medical professionals utilising medical records and interview, it is preferable that the scales chosen be robust enough to withstand this variety of application.

The retrospective coding in use has generally grown from the Abbreviated Injury Scale (AIS) and Injury Severity Scoring (ISS). The guidelines were developed by The Association for the Advancement of Automotive Medicine (Mahue-Giangreco et al. 2001). The AIS divides the body into regions: external, head and face, neck, thorax, pelvic contents, spine, extremities and bony pelvis. Injuries at each location can be classified as minor, moderate, serious, severe, critical and maximum/unknown (Noji et al. 1989). The ISS, which is based on the sum of squares of the highest AIS code in the three most severely injured body regions, can then be applied to come up with a numerical description of the overall severity of injury in patients with multiple injuries. Noji has tried to apply these measures retrospectively to a longitudinal study of a cohort of 12,000 people with hospitalised injuries from the Armenia, 1988 earthquake. In order to use self-report of injury severity, UCLA Center for Public Health and Disasters suggests utilising a rough classification of type of injury into severe, moderate, and minor. Coupled with questions on death and hospitalisation, this yields a rough categorisation of injury certainly good enough for non-medical purposes (Shoaf 2002).

Though this is a definite step in the right direction in categorisation, in some circumstances of mass casualties where medical staff are seriously overstretched, it may be unrealistic to expect the completion of these lengthy forms. However, if captured on post–event questionnaires such as the Cambridge survey where the information on injuries can be extracted, this retrospective coding can be applied with associations to causes of injuries as well.

Some improvements were made to the Cambridge questionnaire over time as preliminary analyses of collected data revealed limitations or confusion in the captured data. Each set of forms was translated into the regional language by the author’s colleagues and local collaborators. In all three cases, there were language and cultural constraints and so help was sought from the local universities in translating the questionnaire as well as providing input in the appropriate questioning techniques. A pilot study carried out in Pakistan 6 months before the main study was a great test for the robustness of the questionnaire. Where there were striking similarities in answers, these became options to questions in the main studies.

16.3 Logistics and Sampling Methodology

Ideally, conventional sampling techniques should be employed with a control set of the non-injured or studies of a group before and after the disaster. Difficulties in implementation of standard data collection methods in an earthquake situation have already been discussed at length and as illustrated in Noji’s book *Public Health Consequences of Disasters* (Noji et al. 1997a), there are many other methodological issues in collecting information post disaster as shown in the list below (taken from Table 3.3 of Noji’s book):

- Compromise between timeliness and accuracy
- Competing priorities for information
- Logistical constraints
- Absence of baseline information
- Denominator data unavailable (population)
- Underreporting of health events
- Lack of representativeness
- Resource costs of collecting and analysing data
- Lack of standardised reporting mechanisms

With these imperfect conditions for surveying it is unlikely that one would be able to conform to standard sampling conditions. Nonetheless, these surveys do give us a rare insight into the experiences unique to a group of people which are unlikely to be captured by other means and therefore, although the methods may be flawed, this does not mean that such data collection should not be attempted. However, in designing a methodology for field data collection after an event, it is important to try and overcome these obstacles and address the issues presented by Noji.

Firstly, it is unrealistic and costly to sample a large number of people and therefore small samples are often interviewed; Noji mentions this lack of representativeness in his list. A sample is said to be representative as long as the group surveyed represents the variability in the population affected by the earthquake (Hammond and McCullagh 1978). The sampling frame in these surveys is the affected area and the sample of 500 families would be randomly selected from two groups within this sampling frame: rural and urban. This would cover the differences in housing types, topography and demographics of the living environment of the affected region.

What is important is finding the denominator data to use as a benchmark and every effort has to be made in gathering baseline information. There may be instances where census data will not be available but the crucial part of this exercise is to make use of local knowledge and previous surveys. In all three sets of surveys carried out by our teams, local collaboration was sought and in doing so, their wealth of local knowledge was intrinsic when analysing the information collected from the field. This was also a way of keeping the costs of collecting the data to a minimum as the local collaboration meant not only that information and techniques were shared but also the costs associated with field surveys.

The timeliness of data collection is intertwined with logistical constraints and unfortunately, there is no real solution to this issue. As fieldwork requires teams to collect data in a situation where there is obvious chaos immediately following the event, there is pressure to postpone data collection. There are several methodological challenges posed by large-scale, rapid-onset disasters. The first is the difficulty of doing anything except ex-post-facto research (Aptekar 1994). We are usually forced to interview disaster victims some time after the event. While some authors have registered concern about the perishable nature of data, others have found that respondents do not forget information, and that some of the data becomes clearer some time after the event (Shoaf and Peek-Asa 2000). Generally speaking, people do remember important events of their life with reliable detail and their memories are fairly consistent over time. Less significant events are not remembered as reliably. Interestingly, the rate of refusal in survey research after large-scale disasters is remarkably low. Noji, for example, in a survey of over 400 respondents had a refusal rate of less than one percent (Noji 1990a, b). It has also been pointed out that survivors are interested in talking about their experiences (Bourque and Fielder 1995). Indeed it may be therapeutic for them to do so though one has to be cautious of people mixing other people's experiences with their own, the design of this questionnaire directs a survivor to recount a sequence, which should help to eliminate false accounts.

16.4 General Issues Arising from the Interviews

The interviews start with an introduction outlining the research aims and informed consent is then sought from the respondents, all in the local language. All interviews were carried out in person and interviewers were visiting homes and temporary housing of survivors. Although it would have been advantageous to tape record these testimonies, it was thought to be inappropriate in the three countries surveyed.

Understanding the questions and the reasons behind the questions was what the author concentrated on when preparing the team in a full-day training session. Each question was discussed at length with the interviewers in Pakistan before they set off in June 2006. Feedback sessions were held after the first 2 days of interviewing after which the team was left to continue independently. Observations were made during the interviews but with the language and cultural barriers, it was less intrusive for the author to be absent. In Indonesia, the training was given only to the coordinator Tri Lindawati from Gadjah Mada University, who was also responsible for translating the questionnaire and for conducting the training of her interviewing team. In Peru, training was given again only to the coordinator Astrid Tolmos of the University of Ica but the form was translated by a Peruvian researcher working in Cambridge.

16.4.1 Ethical Issues

All research that involves human beings assumes risks for the people who agree to participate in it. Although structured interviews are of minimal physical risk, there will certainly be concerns with confidentiality of information given. Furthermore, these interviews were done as part of an investigation and not as an intervention; therefore no help was given in return for the information provided, for example, in the form of advice for re-housing or other means to recovery.

Bearing these issues in mind, when the surveys were conducted, the author followed an ethical protocol as advised by Dr Stephen Platt. The most important aspect was our duty of care to the participants in the research, our informants and the research staff. The ethical statement which was written and approved by all members of the team states:

> *In particular, the research must not harm the people taking part nor intrude on their privacy nor threaten their beliefs. One must be able to assure participants that the information collected will be treated in confidence, that it will not be possible to identify particular individuals in publication of the findings and that personal information will not be released to third parties without their consent. In addition it is good practice to provide participants with a copy of the findings or feedback on the results of the study.*

In order to ensure that the interviewing team did not violate this ethical protocol, an agreement that clarified the obligations and responsibilities was drawn up and signed by the collaborators, where the nature of the investigation was carefully explained. In addition, each member of the interviewing team was also reminded that they must safeguard confidentiality and the welfare of the participants.

The consent of all those who participated in these surveys was sought and the anonymity and purpose of the research was stressed at the start of each interview to every respondent. Respondents were also reminded that they could leave the interview at any time. All subsequent publication of the material collected from these field studies are coherent with the objectives of the investigation and have acknowledged local collaborators.

16.5 Limitations of the Questionnaires

The interviews assembled two different kinds of information, descriptive and factual. In many ways the descriptive accounts provide the best evidence of what occurred and what was observed by the survivor, but this information is difficult to summarise or analyse. There are some limitations to this data set as a representative sample of those affected. For example, we could only interview families who survived. For obvious reasons families with no survivors or those that had migrated could not be interviewed. This could mean there are more reports from people living in better building types, and from those on flatter lands in our data set.

Returned forms for the uninjured were few for Pakistan. This could be due to the bias introduced with the selection of heavily damaged villages in Pakistan or to do with the responders and interviewers not understanding that information on the uninjured and their survival were just as important as those seriously injured. Unfortunately in any kind of survey work, there is always a potential issue of subjective interpretation of questions by interviewers; however in the subsequent surveys in Indonesia and Peru, the responses were more evenly distributed.

In addition, during the development and application of the actual questionnaire forms, several other technical issues arose which are given here:

1. It was imperative to stress that one form was used for each survivor of the household, whether he or she was answering for others or not. Answering for the dead implies the rest of the questionnaire should apply to the victim and therefore in terms of medical treatment, these pages would be left blank. In some cases, it was found that interviewers found it difficult to leave questions unanswered and return a blank form. There were forms which had to be discounted or one had to refer back to field notes to verify which piece of information corresponded to the dead.
2. A central coding system for the questionnaire should have been developed early on with numbering and local traditional modes of building or transport added as extra options at the end of the list rather than changing the entire list. Since no collaborator used FilemakerPro to input data as they were not familiar with the software, they had coded the data individually which required post processing to centralise the information.
3. Interviewers initially found it hard to record multiple-answer questions. In the beta version of the questionnaire, a sentence stating ‘multiple answers are permitted’ was added.

4. Allowing a space for an answer to the option ‘other’ was omitted. This oversight meant that many questionnaire forms had ‘other’, but no qualification of what this answer implied.
5. It would have been useful to have photographs to accompany each questionnaire of the damaged house and village. Although for the first two surveys carried out in Pakistan and Indonesia, due to funding constraints, employing such equipment may not have been possible.

Every attempt was made to monitor the collection of data to ensure any ambiguities were resolved on the outset. In the three surveys, quality control was carried out in the field at the end of every collection day and data entry was carried out as soon as possible into a central system but in processing the information in Cambridge, there were still issues that were evident. For example, there were instances where contradictions were found between the forms and what was recorded on the spreadsheet. Some of these were resolved with field notes but others could not be solved and those records had to be omitted.

16.6 Conclusions

Due to segregation of efforts amongst disciplines, lack of funding and possibly the difficulties in collecting this field data, causal relationships of deaths and injuries from earthquakes have often been inferred from a fusion of information from a variety of sources in a particular event. Recognising a need to collect information after earthquakes to improve global casualty estimation methods, a questionnaire form was designed to capture the sequence of events leading to injuries or deaths after an earthquake.

In total, over 1,200 questionnaire forms were returned for three events, namely the Kashmir earthquake of October 2005, the Yogyakarta earthquake of July 2006 and the Pisco earthquake of August 2007. These were all earthquakes in developing countries where there was widespread damage due to a combination of vulnerable housing under intense shaking. These three earthquakes are typical in so far as the damage was expected, given the seismic intensity levels experienced, but there were some surprising anomalies which can be investigated and explained with these surveys. For example, in Pakistan there were notably more serious injuries surviving beyond the expected period of time; by contrast, the death tolls in Indonesia and Peru were disproportional to the amount of damage observed. Both these atypical facts raise questions as to what the reasons can be.

It is evident from examining past casualty models and reviewing the data collected from recent events that there cannot be generalised casualty rates applied globally for different building types or even for individual countries, as regionally, topography, building techniques and building control all contribute to this multivariant outcome. Therefore new approaches to the problem must include a progressive assessment of what contributes to the final casualty numbers and include other contributory factors.

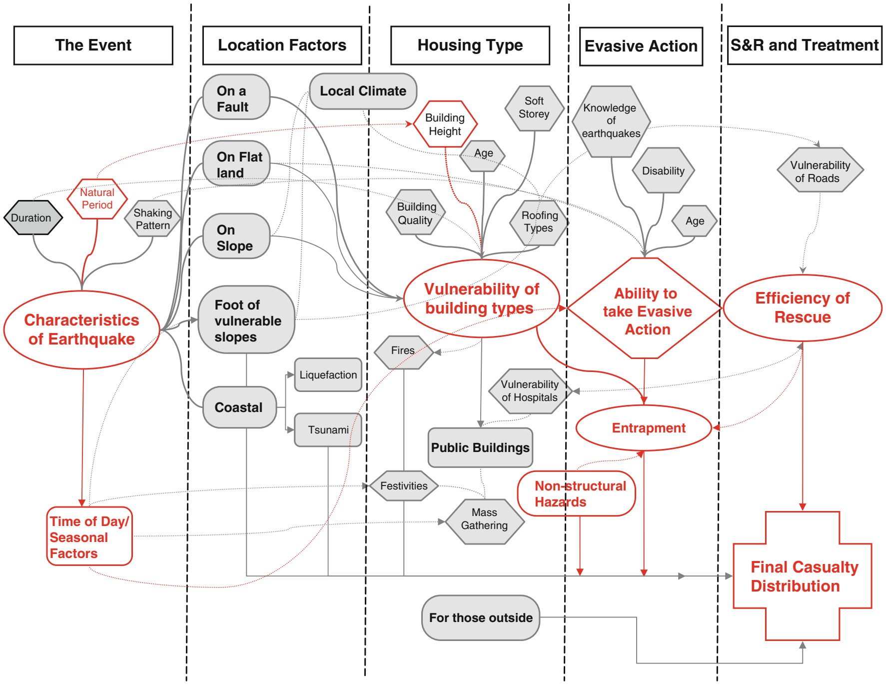


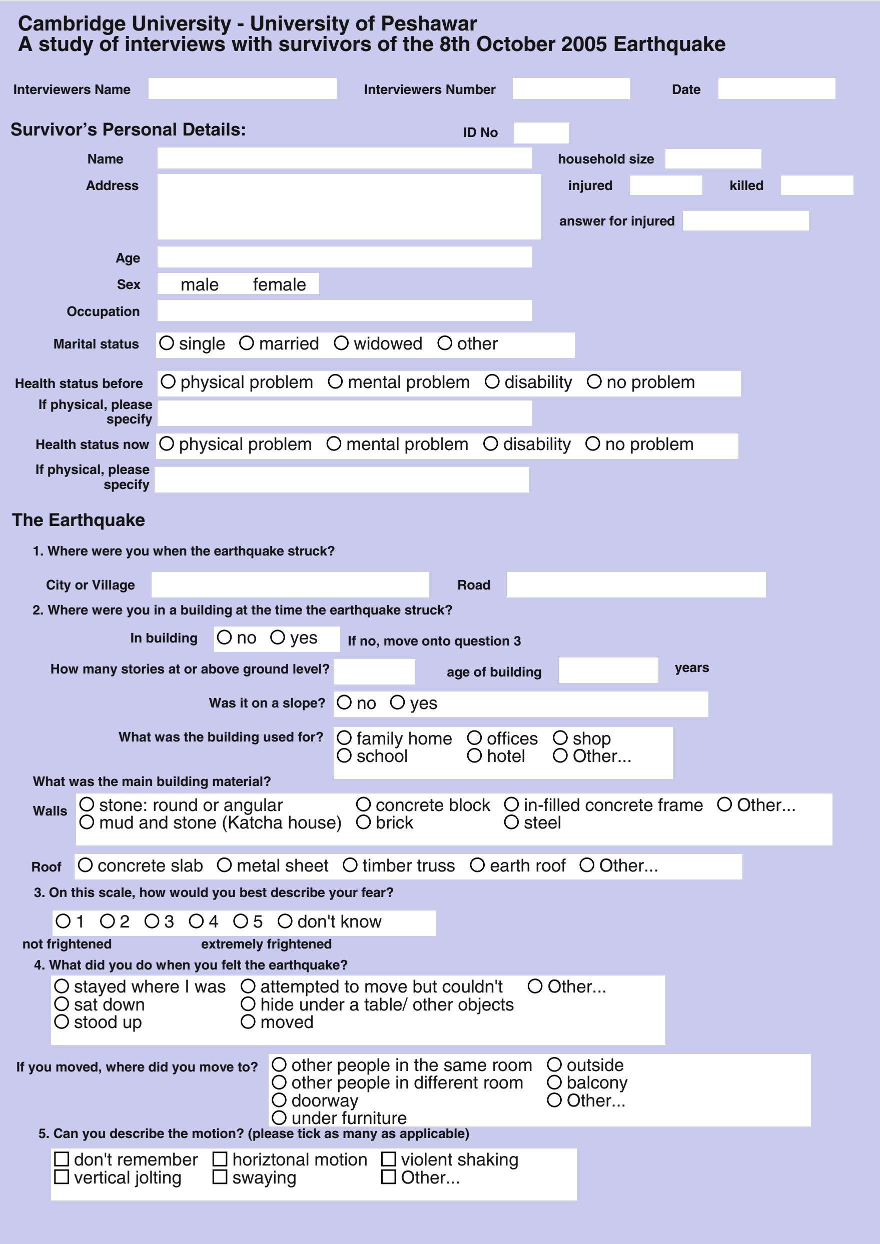
Fig. 16.4 Factors contributing to casualty numbers in a long period ground motion earthquake amplifying motions for high rise buildings on soft soils

Figure 16.4 presents a scenario which may be typical of an earthquake affecting an urban commercial district. Factors which may amplify casualties for this scenario, especially injury numbers, are highlighted in red lines and those in grey are factors that may be important in other situations. This scenario postulates a long period ground motion resonating with tall buildings founded on soft alluvial basin. As shown, the main factor to consider first is the time of day. Are these classes of buildings fully occupied at the time of the postulated event? The second consideration is how many buildings fall in this natural period band and their properties, such as location, occupancy rates, number of floors and distance from hospitals. In this case, buildings are assumed to be built under stringent seismic codes and therefore the building quality option is not highlighted as a factor in the diagram. The main hazard for this scenario is likely to be non-structural in the form of toppling of furniture and false ceilings.

The influences of these contributory parameters and the actual application of these correction factors to loss estimation are being investigated by the author with the USGS in the PAGER project (Wald et al. 2009). Correlations derived from surveys, capturing empirical information from recent events are invaluable for these ongoing analyses.

Although there were limitations to the surveying methods and data collected from the questionnaire surveys and interviews, this is seen to be a significant step towards a globally generic form especially designed to improve understanding of earthquake injury epidemiology and casualty estimation. It is hoped that this will be the start of a standardised method and implementation which will be developed and employed in future events.

Acknowledgments The author would like thank her mentors for this work, Professor Robin Spence and Dr Marla Petal, who provided some of the reference text. Very special thanks also go to her local collaborators and their survey teams in Pakistan, Indonesia and Peru: Professor Amir Khan, Tri Lindawati and Astrid Tolmos. Without them, this research would not have been possible.



Cambridge University - University of Peshawar
A study of interviews with survivors of the 8th October 2005 Earthquake

Interviewers Name **Interviewers Number** **Date**

Survivor's Personal Details: **ID No**

Name **household size**
Address **injured** **killed**
answer for injured
Age
Sex male female
Occupation
Marital status ○ single ○ married ○ widowed ○ other

Health status before ○ physical problem ○ mental problem ○ disability ○ no problem
If physical, please specify
Health status now ○ physical problem ○ mental problem ○ disability ○ no problem
If physical, please specify

The Earthquake

1. Where were you when the earthquake struck?

City or Village **Road**

2. Where were you in a building at the time the earthquake struck?

In building ○ no ○ yes **If no, move onto question 3**
How many stories at or above ground level? **age of building** **years**
Was it on a slope? ○ no ○ yes
What was the building used for? ○ family home ○ offices ○ shop
○ school ○ hotel ○ Other...

What was the main building material?

Walls ○ stone: round or angular ○ concrete block ○ in-filled concrete frame ○ Other...
○ mud and stone (Katcha house) ○ brick ○ steel

Roof ○ concrete slab ○ metal sheet ○ timber truss ○ earth roof ○ Other...

3. On this scale, how would you best describe your fear?

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ don't know
not frightened **extremely frightened**

4. What did you do when you felt the earthquake?

○ stayed where I was ○ attempted to move but couldn't ○ Other...
○ sat down ○ hide under a table/ other objects
○ stood up ○ moved

If you moved, where did you move to? ○ other people in the same room ○ outside
○ other people in different room ○ balcony
○ doorway ○ Other...
○ under furniture

5. Can you describe the motion? (please tick as many as applicable)

☐ don't remember ☐ horiztonal motion ☐ violent shaking
☐ vertical jolting ☐ swaying ☐ Other...

Injury Data

6. Were you injured or anyone with you injured or killed? ○ no ○ yes

Number injured **Number killed**

additional injury info

Please repeat the questionnaire for the others in the family or group if possible.

7. When were you injured?

○ during the earthquake ○ during an aftershock ○ during the clean up operation
○ just after the earthquake ○ during search and rescue ○ Other...

8. What were you doing when you were injured?

○ exiting the building ○ waiting for rescue ○ after search and rescue ○ Other...
○ running downstairs ○ waiting for medical attention ○ after medical treatment

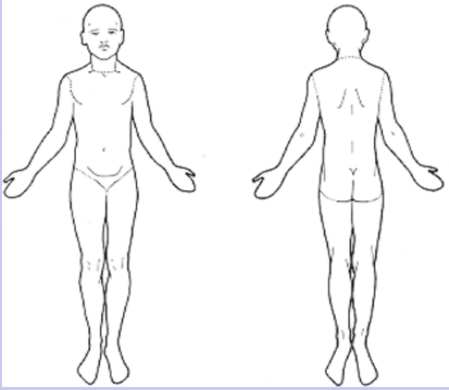
9. Type of injury/injuries (please tick more than one if mutliple):

☐ minor cuts
☐ bruises
☐ sprain or strain
☐ superficial injury
☐ dehydration (> 6hrs)
☐ dislocations of joints
☐ cuts in soft tissue
☐ open wounds
☐ crushing injury
☐ foreign body in eye, ear, nose, thorat or other orifice
☐ burns
☐ uncontrolled bleeding
☐ poisoning (chemical)
☐ injury to major blood vessels
☐ fracture on neck or torso
☐ pelvic fracture
☐ upper extremity fracture
☐ lower extremity fracture
☐ head injury
☐ internal injury
☐ brain injury or skull fracture
☐ injury to nerves, spinal cord
☐ kidney problems or failure
☐ Other...

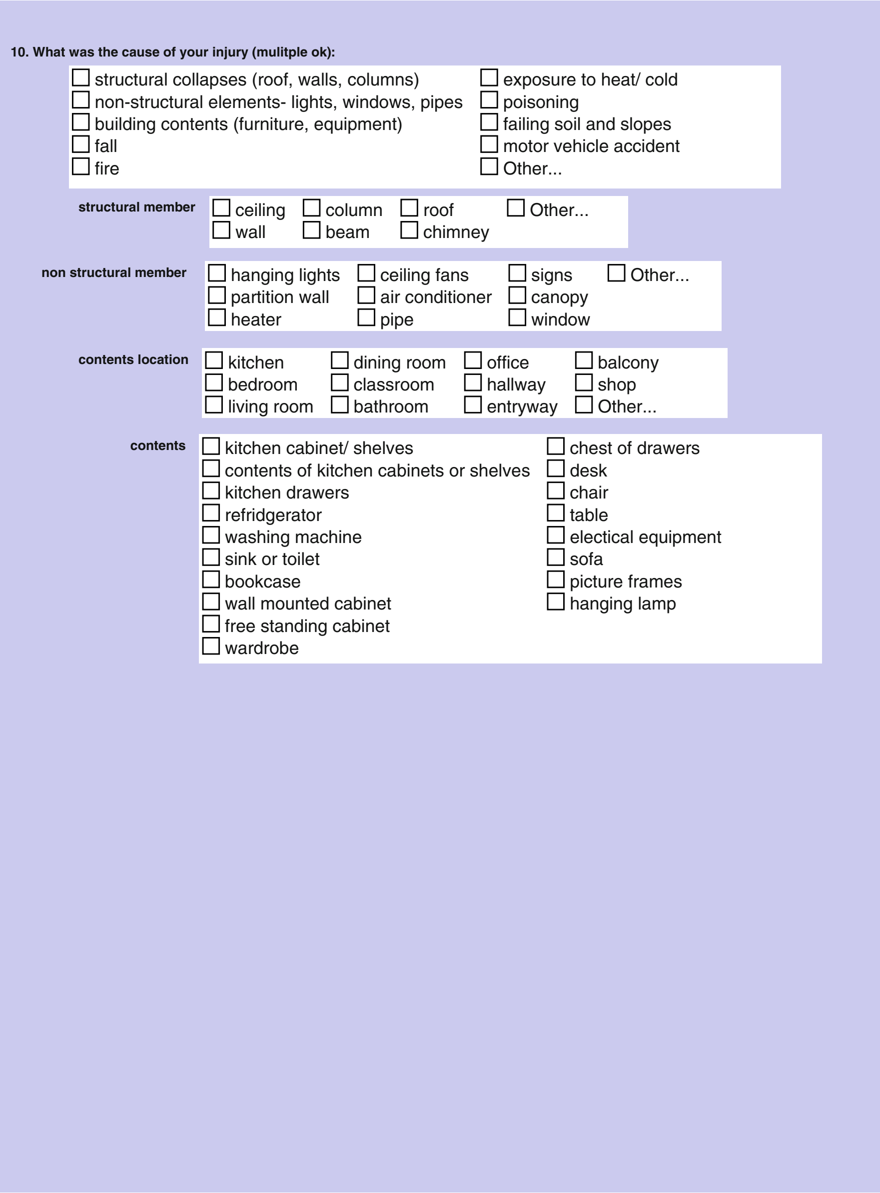
Please mark on the diagrams below and use the following key, where possible/ known of injuries caused at the time:

Key:

\# = fracture
O = contusion
/ = laceration
____ = amputation
/./ = other



Other forms of injuries



10. What was the cause of your injury (mulitple ok):

☐ structural collapses (roof, walls, columns)
☐ non-structural elements- lights, windows, pipes
☐ building contents (furniture, equipment)
☐ fall
☐ fire
☐ exposure to heat/ cold
☐ poisoning
☐ failing soil and slopes
☐ motor vehicle accident
☐ Other...

structural member

☐ ceiling
☐ wall
☐ column
☐ beam
☐ roof
☐ chimney
☐ Other...

non structural member

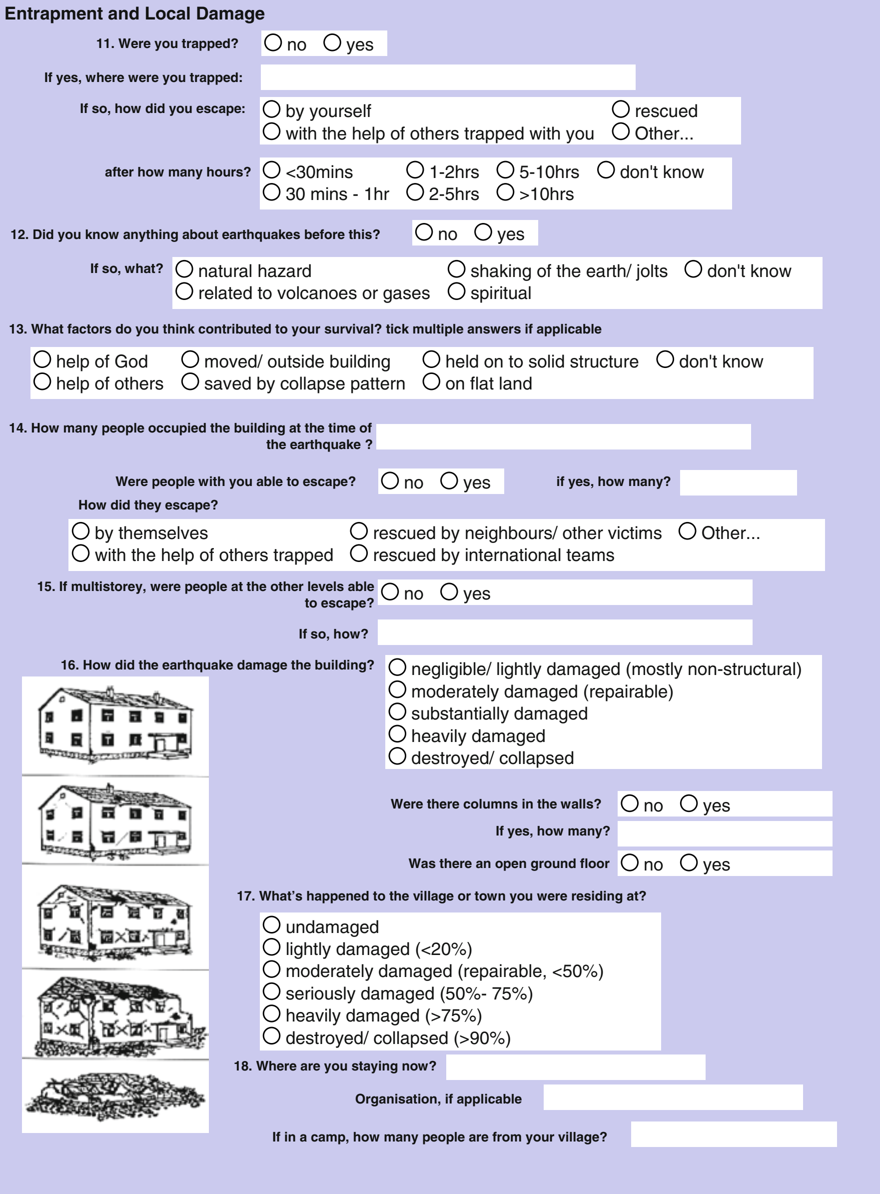
☐ hanging lights
☐ partition wall
☐ heater
☐ ceiling fans
☐ air conditioner
☐ pipe
☐ signs
☐ canopy
☐ window
☐ Other...

contents location

☐ kitchen
☐ bedroom
☐ living room
☐ dining room
☐ classroom
☐ bathroom
☐ office
☐ hallway
☐ entryway
☐ balcony
☐ shop
☐ Other...

contents

☐ kitchen cabinet/ shelves
☐ contents of kitchen cabinets or shelves
☐ kitchen drawers
☐ refridgerator
☐ washing machine
☐ sink or toilet
☐ bookcase
☐ wall mounted cabinet
☐ free standing cabinet
☐ wardrobe
☐ chest of drawers
☐ desk
☐ chair
☐ table
☐ electical equipment
☐ sofa
☐ picture frames
☐ hanging lamp



Entrapment and Local Damage

11. Were you trapped? ○ no ○ yes

If yes, where were you trapped:

If so, how did you escape:
○ by yourself ○ rescued
○ with the help of others trapped with you ○ Other...

after how many hours?
○ <30mins ○ 1-2hrs ○ 5-10hrs ○ don't know
○ 30 mins - 1hr ○ 2-5hrs ○ >10hrs

12. Did you know anything about earthquakes before this? ○ no ○ yes

If so, what?
○ natural hazard ○ shaking of the earth/ jolts ○ don't know
○ related to volcanoes or gases ○ spiritual

13. What factors do you think contributed to your survival? tick multiple answers if applicable
○ help of God ○ moved/ outside building ○ held on to solid structure ○ don't know
○ help of others ○ saved by collapse pattern ○ on flat land

14. How many people occupied the building at the time of the earthquake ?

Were people with you able to escape? ○ no ○ yes **if yes, how many?**

How did they escape?
○ by themselves ○ rescued by neighbours/ other victims ○ Other...
○ with the help of others trapped ○ rescued by international teams

15. If multistorey, were people at the other levels able to escape? ○ no ○ yes

If so, how?

16. How did the earthquake damage the building?
○ negligible/ lightly damaged (mostly non-structural)
○ moderately damaged (repairable)
○ substantially damaged
○ heavily damaged
○ destroyed/ collapsed

Were there columns in the walls? ○ no ○ yes

If yes, how many?

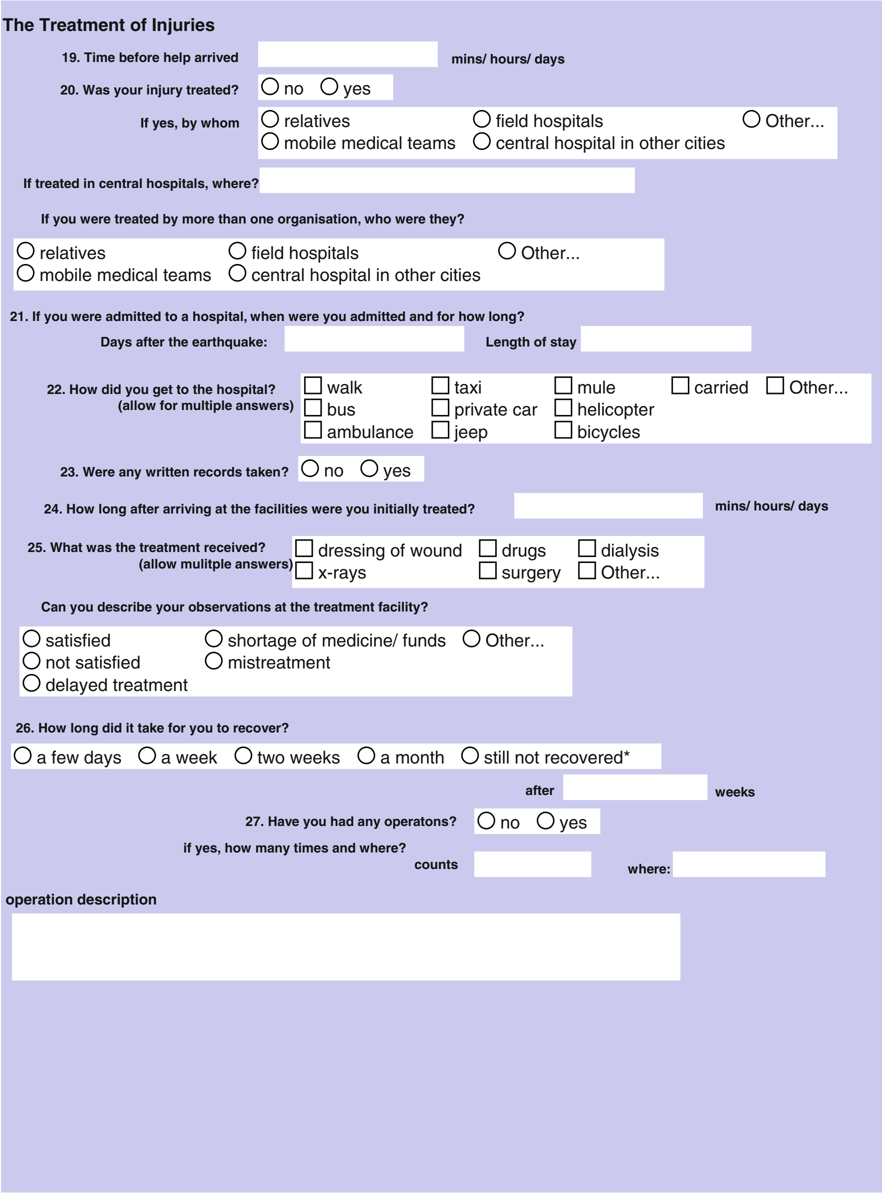
Was there an open ground floor ○ no ○ yes

17. What's happened to the village or town you were residing at?
○ undamaged
○ lightly damaged (<20%)
○ moderately damaged (repairable, <50%)
○ seriously damaged (50%- 75%)
○ heavily damaged (>75%)
○ destroyed/ collapsed (>90%)

18. Where are you staying now?

Organisation, if applicable

If in a camp, how many people are from your village?



The Treatment of Injuries

19. Time before help arrived ______ mins/ hours/ days

20. Was your injury treated? ○ no ○ yes

If yes, by whom ○ relatives ○ field hospitals ○ Other... ○ mobile medical teams ○ central hospital in other cities

If treated in central hospitals, where? ______

If you were treated by more than one organisation, who were they?

○ relatives ○ field hospitals ○ Other...
○ mobile medical teams ○ central hospital in other cities

21. If you were admitted to a hospital, when were you admitted and for how long?

Days after the earthquake: ______ Length of stay ______

22. How did you get to the hospital? (allow for multiple answers)
☐ walk ☐ taxi ☐ mule ☐ carried ☐ Other...
☐ bus ☐ private car ☐ helicopter
☐ ambulance ☐ jeep ☐ bicycles

23. Were any written records taken? ○ no ○ yes

24. How long after arriving at the facilities were you initially treated? ______ mins/ hours/ days

25. What was the treatment received? (allow mulitple answers)
☐ dressing of wound ☐ drugs ☐ dialysis
☐ x-rays ☐ surgery ☐ Other...

Can you describe your observations at the treatment facility?

○ satisfied ○ shortage of medicine/ funds ○ Other...
○ not satisfied ○ mistreatment
○ delayed treatment

26. How long did it take for you to recover?

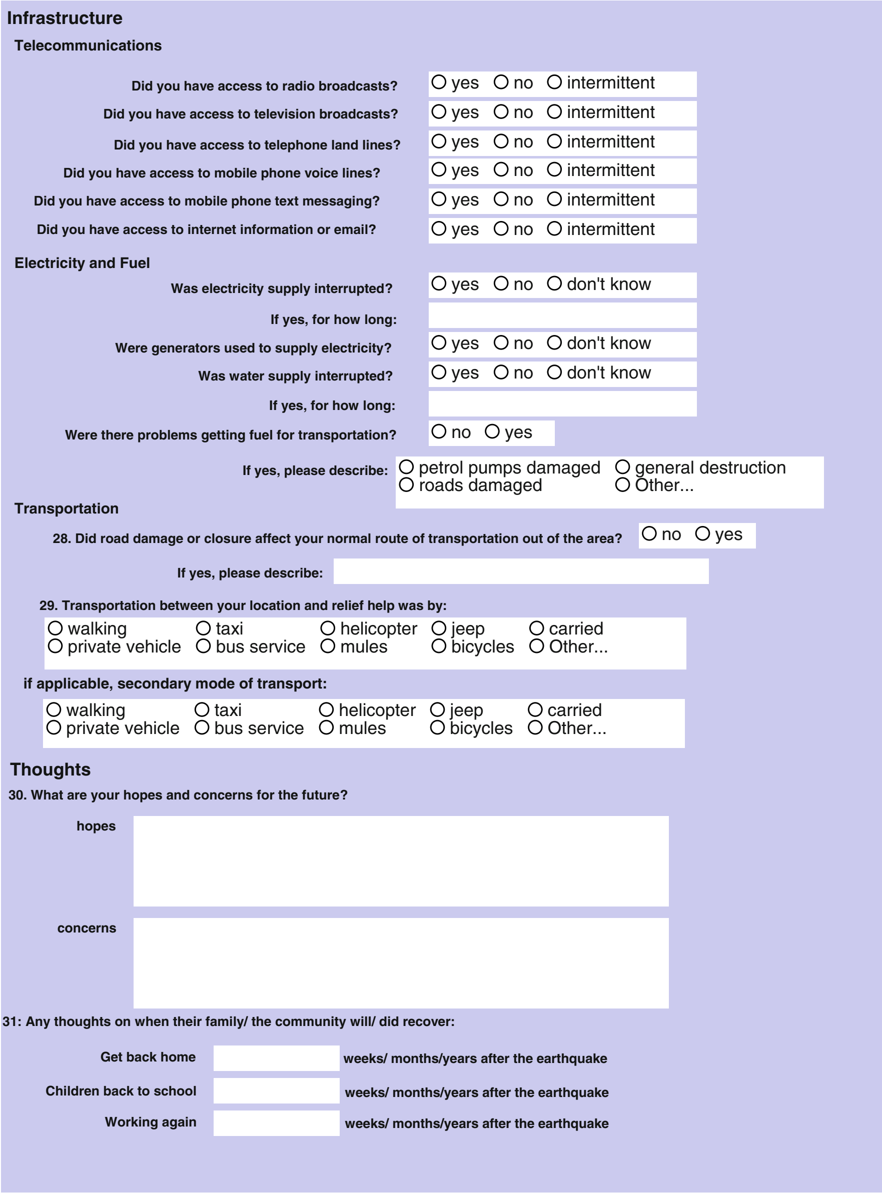
○ a few days ○ a week ○ two weeks ○ a month ○ still not recovered*

after ______ weeks

27. Have you had any operatons? ○ no ○ yes

if yes, how many times and where?
counts ______ where: ______

operation description



Infrastructure

Telecommunications

Did you have access to radio broadcasts?	○ yes ○ no ○ intermittent
Did you have access to television broadcasts?	○ yes ○ no ○ intermittent
Did you have access to telephone land lines?	○ yes ○ no ○ intermittent
Did you have access to mobile phone voice lines?	○ yes ○ no ○ intermittent
Did you have access to mobile phone text messaging?	○ yes ○ no ○ intermittent
Did you have access to internet information or email?	○ yes ○ no ○ intermittent

Electricity and Fuel

Was electricity supply interrupted?	○ yes ○ no ○ don't know
If yes, for how long:	
Were generators used to supply electricity?	○ yes ○ no ○ don't know
Was water supply interrupted?	○ yes ○ no ○ don't know
If yes, for how long:	
Were there problems getting fuel for transportation?	○ no ○ yes
If yes, please describe:	○ petrol pumps damaged ○ roads damaged ○ general destruction ○ Other...

Transportation

28. Did road damage or closure affect your normal route of transportation out of the area?	○ no ○ yes
If yes, please describe:	

29. Transportation between your location and relief help was by:

○ walking	○ taxi	○ helicopter	○ jeep	○ carried
○ private vehicle	○ bus service	○ mules	○ bicycles	○ Other...

if applicable, secondary mode of transport:

○ walking	○ taxi	○ helicopter	○ jeep	○ carried
○ private vehicle	○ bus service	○ mules	○ bicycles	○ Other...

Thoughts

30. What are your hopes and concerns for the future?

hopes	
concerns	

31: Any thoughts on when their family/ the community will/ did recover:

Get back home		weeks/ months/years after the earthquake
Children back to school		weeks/ months/years after the earthquake
Working again		weeks/ months/years after the earthquake

Chapter 17
Estimating Human Losses in Earthquake Models: A Discussion

M.A. Ferreira, C.S. Oliveira, and F. Mota de Sá

Abstract Several studies and methodologies have been developed in recent years to model the number of victims and injuries caused by natural disasters such as earthquakes. Unfortunately, models and simulations developed up to now show substantial variability in the numbers of victims when compared with real values, because they do not consider a multi-parameter analysis including variables such as seismic intensity, degrees of building damage, percent of occupancy at the time of the event, individual behaviour (age, gender, mobility within the house during the shaking, etc.) or emergency response (effectiveness in response). When dealing with this topic we should separate the situation of estimation of human losses for emergency preparedness from the estimation right after a given event. In this paper the second of these issues will be analysed. People's reactions prior to and during the shaking together with the building behaviour cause great differences in the number of deaths and injuries for a given earthquake. The European Macroseismic Scale (EMS-98) provides five grades for damage classification from "Negligible to slight" damage (D1) to "Collapse" (D5). While D5 class includes total or near total collapse of the buildings, we propose a class $D5^+$ to represent "totally collapsed" structures separately from "almost collapsed" so as to establish a direct relation between damage grade and death rate. Data from a few events in Portugal and Italy illustrate the difficulties in estimating human losses.

17.1 Background

Outcomes of models and simulations developed to estimate casualties (fatalities and injuries) caused by natural events like earthquakes show systematically large differences between modelled and observed values. This paper examines some

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factors that lead to earthquake casualties as well as some conclusions obtained from recent earthquakes that can be incorporated into epidemiological studies in order to contribute to an improved rapid casualty assessment. Note that when dealing with this topic, the estimation of human losses for emergency preparedness should be separated from the estimation done immediately after a given event, such as we do in this paper.

Accuracy of the model for earthquake casualties depends clearly on the rate of occupancy and on the damage state of a building. We cannot advance with any reliable estimate if these two ingredients are not present. A more adequate description of the building damage, especially considering total collapse as well as the rate of occupancy at the time of the event are crucial elements for a more realistic estimation. For the first point, census information on building classes should be always updated especially on new construction and replacement of old construction. Totally collapsed reinforced concrete buildings may be responsible for up to 100% of the occupants' deaths. For this reason we propose a new damage level, '$D5^+$' which corresponds to this damage level, solving the controversy in language between collapse in structural analysis which means "imminence of collapse", and real total collapse as we should have in estimating the death toll.

In relation to the population inside the building, a "building occupancy" indicator is proposed, which measures the percentage of the population inside the building at the time of the earthquake. Census information is very crude and possibly misleading. For instance, in the Algarve, the southernmost significant region in mainland Portugal, where important active faults exist and the most important Portuguese earthquakes (1755, 1969, etc.) were felt and severely damaged this region, we see that the Census does not have a count of population that includes, for example, seasonal fluctuations and mobility. This region is a very popular destination for tourists (mainly from Britain, Germany and other North European countries), which suggests that there are real differences in the demography during the year, once tourism and related activities increase in summer. In fact, the Algarve population during summer in some towns, like Albufeira or Portimão, is almost three times the Census values.[1] Another example is related to tourist centres where population numbers could easily double, as for example in Faial Island (Azores) during the Sea Week Festival (between the first and second Sundays of August) where more than 12,000 people are present, while the Census indicates only 5,000 residents (Oliveira et al. 2008).

But the problem of getting the "building occupancy" indicator at the time of the event is much more complex than simply having a good estimator of mobility. It also has to do with anticipation of the event which can disperse the population from their houses to other places where they feel safer, as has happened in recent events where foreshocks were felt.

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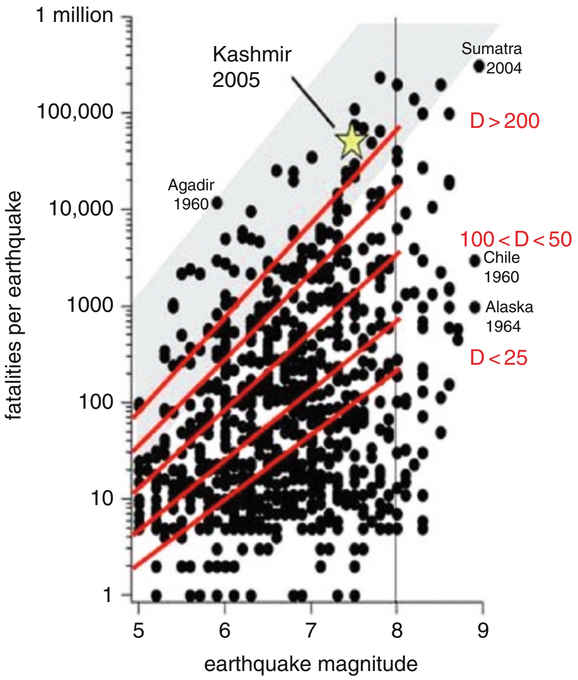
[1] A recent study on dynamics of population was made within a Project for the Algarve [ERSTA], sponsored by the ANPC, the Portuguese Authority for Civil Protection, in which investigations of population mobility were carried out.

Fig. 17.1 Relation between earthquake magnitude and numbers of fatalities for all earthquakes since 1900 (Hough and Bilham 2006) with lines adapted from Samardjieva and Badal 2002 (D is population density per km^2)



Figures 17.1 and 17.2 illustrate different measures of the distribution of the fatalities in earthquakes in the last century. Figure 17.1 shows that fatalities grow with magnitude starting with M5, but with such a wide dispersion that many variables need to be considered in the process to reduce uncertainties to a reasonable value. One improvement has been made by Samardjieva and Badal (2002), introducing the population density of the affected locations. Correlation with heavily damaged buildings is slightly better (Fig. 17.2) but dispersion is still so large (in some cases attaining almost five orders of magnitude) that those values are of no use in simulation. In fact, the simplified approach (Bramerini et al. 1995) that proposes a mean value of victims – casualties and severely injured – (e.g. 30% of the occupants of collapsed buildings) does not represent a reasonable rule for estimating victims, even though Fig. 17.2b) may support this assertion in average terms.

Although the fatal consequences of large earthquakes depends on their proximity to urban populations, the vulnerability of dwellings including the construction type and quality and population density (Hough and Bilham 2006) (Fig. 17.3), it is also certain that some variables like “building occupancy” and “population dynamics” during the day, weekends and for different periods of the year, cannot be discarded in these studies and estimations.

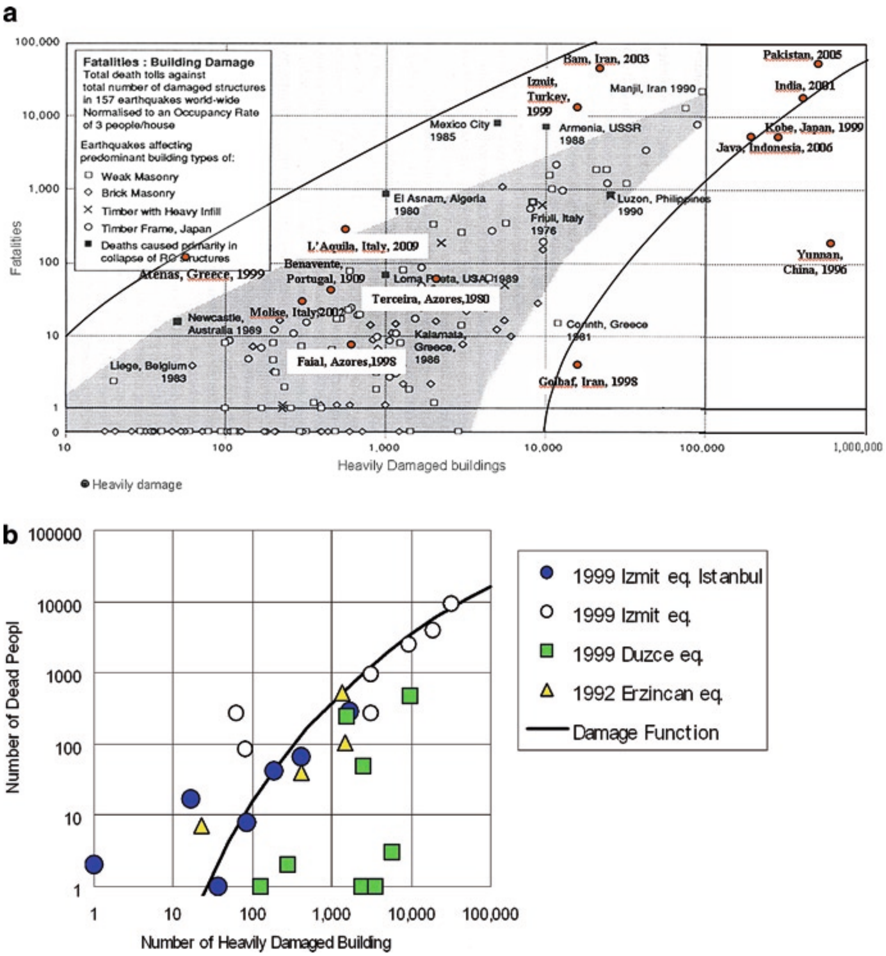


Fig. 17.2 Relation between heavily damaged buildings and the number of resulting deaths: (**a**) adapted from Coburn and Spence 2002; (**b**) Erzincan and Izmit earthquakes (Mouroux and Le Brun 2006)

17.2 Results from Recent Earthquakes

17.2.1 L'Aquila Earthquake (Italy)

On 6 April, 2009 at 03.32, an earthquake (M_L 5.8) rocked the mountainous Abruzzo region of central Italy reaching a maximum intensity of IX–X on the Mercalli-Cancani-Sieberg scale (Fig. 17.4).

Obituary data from the regional newspaper (www.ilcentro.it) were analysed and a database was constructed with all the related information: place of death (sometimes with the exact address), age, nationality, gender, and other variables

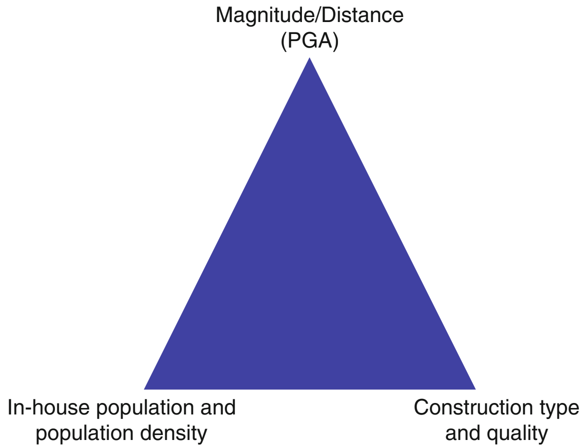
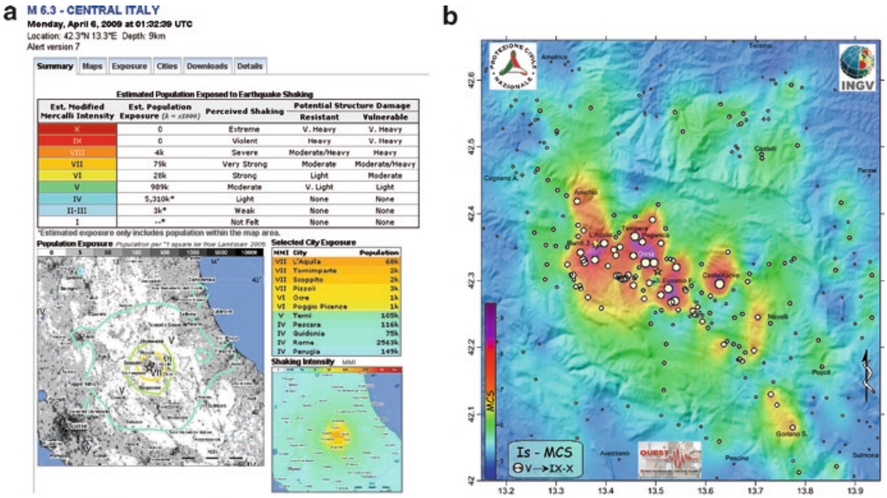


Fig. 17.3 Main variables influencing human losses estimations



M 6.3 - CENTRAL ITALY
Monday, April 6, 2009 at 01:32:39 UTC
Location: 42.3°N 13.3°E Depth: 9km
Alert version 7

Summary | Maps | Exposure | Cities | Downloads | Details

Estimated Population Exposed to Earthquake Shaking

Est. Modified Mercalli Intensity	Est. Population Exposure (k = x1000)	Perceived Shaking	Potential Structure Damage	
			Resistant	Vulnerable
X	0	Extreme	V. Heavy	V. Heavy
IX	0	Violent	Heavy	V. Heavy
VIII	4k	Severe	Moderate/Heavy	Heavy
VII	79k	Very Strong	Moderate	Moderate/Heavy
VI	28k	Strong	Light	Moderate
V	989k	Moderate	V. Light	Light
IV	5,310k*	Light	None	None
II-III	3k*	Weak	None	None
I	--*	Not Felt	None	None

*Estimated exposure only includes population within the map area.

Population Exposure

Selected City Exposure

MMI	City	Population
VII	L'Aquila	68k
VII	Tornimparte	2k
VII	Scoppito	2k
VII	Pizzoli	3k
VI	Ocre	1k
VI	Poggio Picenze	1k
V	Terni	105k
IV	Pescara	116k
IV	Guidonia	75k
IV	Roma	2563k
IV	Perugia	149k

Shaking Intensity MMI

PAGER (Prompt Assessment of Global Earthquakes for Response), Imax=VII (www.usgs.com)

Real intensities obtained after some analysis (Galli and Camassi, 2009) Imax=IX-X

Fig. 17.4 Comparison between estimated and real L'Aquila intensities

(Ferreira 2009). On 20 May the estimated number of victims was 306, including 22 children (from 4 months-old to 14 years old). The earthquake also caused 1,500 injuries (10% severely injured). According to Italian Civil Protection reports, around 62,200 persons were homeless: 24,300 were being housed in hotels near the Adriatic Coast, 9,400 found accommodation with friends or relatives, and 28,500 were living in tent villages (www.protezionecivile.it, 21 May, 2009). Once the large amount of data has been compiled and analysed, a wide range of discussion opportunities were made available on certain topics from causes for the discrepancies between mortality in masonry or concrete buildings, male and female age of death, student mortality causes and much more. Some of these topics are considered in this section.

Figure 17.4 shows that there is a difference of two or three intensity scale points between a rapid intensity assessment and an observed intensity value obtained after fieldwork by INGV. We should emphasise that the simulation is a crude representation of reality because it does not include the various circumstances that characterise not only the real fault rupture mechanism but also the distribution of the population at the time of the earthquake. Of course, simulators are important to give an idea – within a few minutes of the earthquake's occurrence – about the potential of the impact consequences.

17.2.1.1 Post-Earthquake Numbers

The vast information assembled from the World Wide Web (Ferreira 2009) has contributed to an understanding of the relatively low death toll as well as other information freely available and updated. Figure 17.5 summarises the evolution of the number of fatalities during the first week from 6 to 13 April, 2009.

According to the 2007 Census (www.comuni-italiani.it) the population of L'Aquila province is 72,500; if we divided the total number of deaths by the total population we obtained a mortality rate of 0.42%. It is also clear that the number of female casualties is higher than male, suggesting a different behaviour during the earthquake shaking.

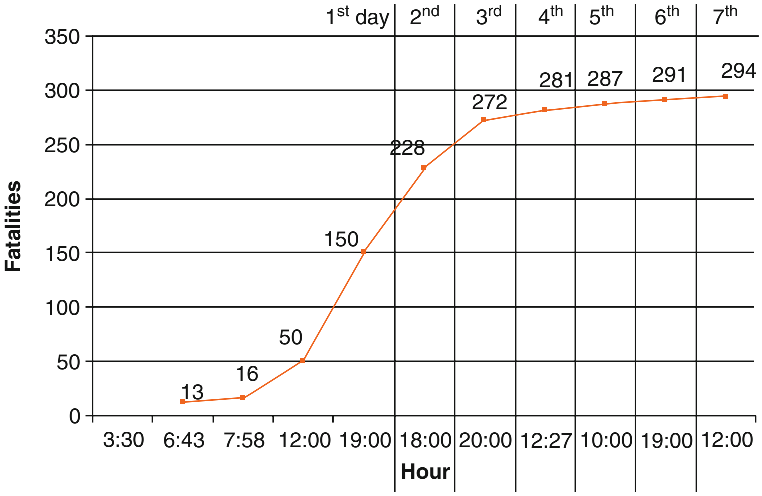


Fig. 17.5 Estimates of the number of victims during the first week (Ferreira 2009)

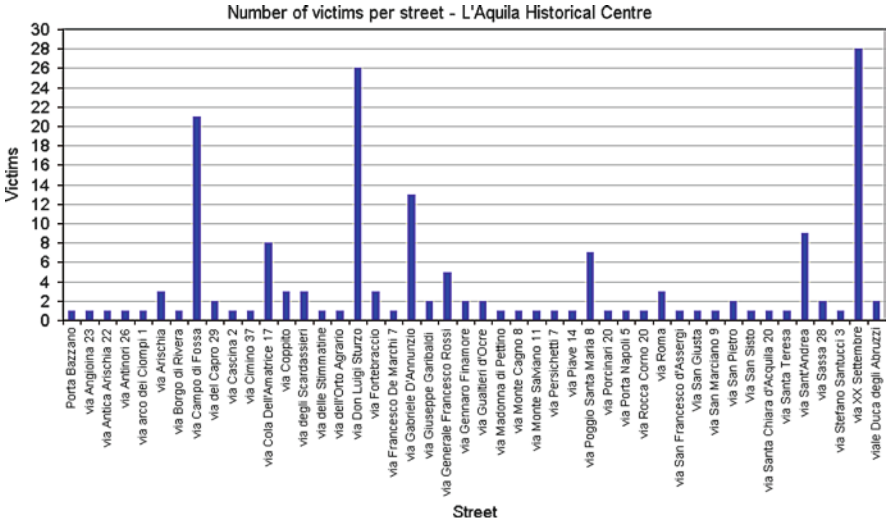


Fig. 17.6 Number of victims per street – L'Aquila Historical Centre ("Il Centro" newspaper)

In L'Aquila historical centre where 199 people died, the pattern was essentially 6–8 deaths per totally collapsed building, here identified as D5^{+} damage level. Counting only these, one arrives at about 30–40% casualty rate for buildings having D5^{+}. The worst conditions were 10–14 fatalities per building, which occurred on Via Campo di Fossa 6–6B, Via XX Settembre (Casa dello Studente – dormitory of the University of L'Aquila – with 11 fatalities) or at Via Don Luigi Sturzo, 39, where ten victims were found. Figure 17.6 illustrates the number of victims per street. The other 100 deaths were groups of 1–2 persons spread throughout the region. The number of deaths in localities situated in the valley (near the fault trace) was about 1–3 per locality (rural areas) with the exception of Onna and Villa Sant'Angelo where the death toll must have been 1–3 per collapsed building.

17.2.1.2 Understanding the Death Toll

Despite the considerable destruction that has occurred in L'Aquila province, relatively low casualty rates were verified and could be explained by:

1. Felt seismicity in the 2 months before the earthquake frightened many people and some of them had decided to sleep outside. On 30 March 2009, for example, some panic occurred among the L'Aquila population due to several shocks, forcing the closing of four schools after a technical inspection which demonstrated moderate damage to these structures. L'Aquila University was also closed and the *Casa dello Studente* was evacuated for 3 hour after the 30 March event. The warning announced by Giampaolo Giuliani from Laboratori Nazionali del Gran Sasso (although the earthquake occurred about a week later than he had

Fig. 17.7 Onna aerial view showing the damage to the building stock

predicted and at another locality – Sulmona about 70 km south of L'Aquila) and the foreshock 4 hour before the main event also contributed to saving a great number of lives (Ferreira 2009). A few families moved house in order to feel more secure close to their relatives or were camping in their own gardens or sleeping in the cars near their homes.

2. Many houses in L'Aquila are second homes used only at weekends. The earthquake occurred on Monday at 03.32 h when many such people were in their main homes out of L'Aquila.

By contrast, high mortality was verified among young people, students that returned back from the weekend to L'Aquila and were caught by the earthquake in their apartments or *Casa dello Studente*. Also, high mortality was observed in highly vulnerable rural or semirural areas with a poorly built environment like Onna, where among 350 inhabitants living in 150 houses (1–3 storeys) there were 40 deaths, corresponding to a death ratio of 11%. A preliminary Onna assessment (aerial view) indicates that about 50% of the building stock suffered total collapse ($D5^+$) (Fig. 17.7).

17.2.2 Azores and Benavente Earthquakes (Portugal)

In this section we present casualty information on a few earthquakes that shook mainland Portugal and the Azores islands during the last century. In Portugal, for low rise masonry buildings the rate of mortality according to historical data is very small, either on the Continent or the Azores, with the exception of the 1755 Lisbon event. In rural and historical urban areas analysed, the construction typology is very similar throughout the different geographic regions of Portugal, though with some differences in materials which are region-dependent; the population habits are also very similar throughout Portugal.

17.2.2.1 Azores Earthquakes

The Azores archipelago is a high seismicity region due to its geographical location, near the triple junction of the Euro-Asian, African and American plates (Fig. 17.8). The M_w 7.2 Azores earthquake that occurred on 1 January 1980 devastated Terceira, São Jorge and Graciosa islands at 16.42 h causing a death rate of 0.1% of a total population of 60,000 affected by Intensity(MMI) greater than V. At the time of the earthquake, many people were outside in the streets and consequently the building occupancy was very small. Sixty-three people died.

The 1998 Faial earthquake which measured M_w 6.2 caused eight deaths, hundreds of injuries, and 2,500 homeless. In Faial 35% of the buildings were affected (at damage grade from D1 to D5); in Pico 10% of buildings were affected. The housing stock is predominantly one to two-storey stone masonry houses. Death and injury rates were very low (death rate: 0.05% of the population of 15,000) considering the immense damage observed.

The authors believe that the following factors may have been responsible for this low death rate:

Fig. 17.8 Main seismicity in Azores Archipelago Central Group with epicentral locations of earthquakes from 1757–1998

1. As a direct consequence of emigration a high number of houses are secondary homes (seasonal), with no occupants during July. Some buildings have been abandoned for years and an old and vulnerable housing stock appeared to be contributing to the damage.
2. The outwards collapse of outer walls, leaving in place the inner partition walls which protected the inhabitants from the fall of roofs (the earthquake occurred at 05.00 h when most of the inhabitants were sleeping or still in their homes).
3. A foreshock took place 20 min before the main shock, which probably initiated some individual escape action.

17.2.2.2 The Benavente Earthquake

Benavente is a municipality of continental Portugal where the M_w 6.2 1909 earthquake, caused by rupture in the Lower Tagus Valley Fault Zone, destroyed a few villages. A maximum intensity of VIII–IX (EMS-92) was felt in Benavente and VI–VII (EMS-92) in Lisbon (Fig. 17.9).

Benavente municipality in 1909 had a population of 3,557 inhabitants and about 400 buildings (950 dwellings). The earthquake killed 30 people, 0.8% of this total population, and 40% of housing stock was demolished.

The authors believe that the apparent low impact in lives was caused by:

1. Time of day. At 17.00 h a majority of the inhabitants, mostly agricultural workers, were out in the open, working on their land.
2. Roofs and partition walls survived, with no collapse, though the outer walls of buildings collapsed, killing a few children that were playing near the houses (Rodrigues D'Azevedo 1926).

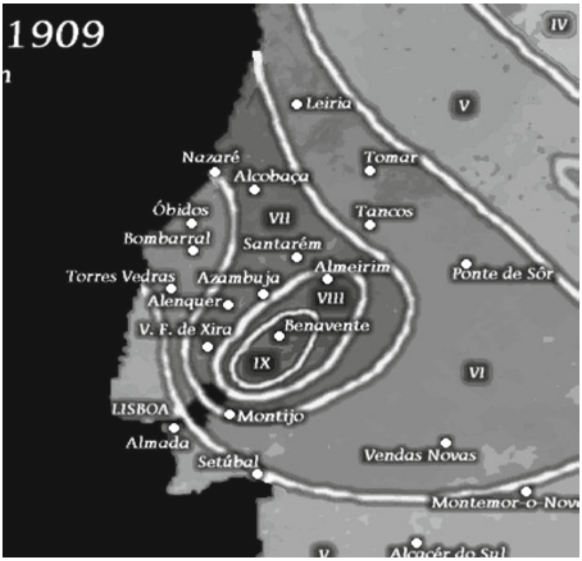


Fig. 17.9 Benavente isoseismal map (Moreira 1984)

17.3 Human Casualty Models: Making the Count Right

Ensuring a fair and accurate population count is one of the key components to developing human casualty models. Human casualty models should be looked from two different perspectives:

1. To design a system for civil protection, insurance, urban planning, etc., where a population scenario has to be developed, population dynamics have to be included for a more adequate model.
2. For rapid casualty assessment and emergency response in the case of a given earthquake, it is important to develop a human behaviour model in order to produce better results than the ones obtained with current scenarios/models. Apart from the population dynamics by time of day and season, to give more consistent information the model should include, among others, the following "building occupancy" indices:

   - Signs of prediction
   - Early-perception
   - Panic reaction

These indices are very difficult to determine, but the examples presented in Section 17.2 show how critical they may be for a more accurate estimation of human casualties.

When analysing complex topics, we have to avoid over-simplification of the problem, losing sight of the relevant aspects of it and losing sight of the target problem. Thus, mortality rate computations cannot be explained in a straightforward manner using only the Census data due to the fact that mobility, for example, is not taken into account in many cases. In addition, as referred to above, other factors can significantly influence the "building occupancy" index.

In a tentative effort to give indications of human losses for masonry and reinforced concrete buildings, after a simplified analysis of damage grades observed during several earthquakes we concluded that:

1. For masonry buildings the chances of survival for $D5^+$ look higher than in RC buildings.
2. For RC buildings, total collapse ($D5^+$) means a small chance of survival and, consequently, very high values of mortality rate (as high as 70%) as is well demonstrated in the recent Haiti M7.0 earthquake (12 January, 2010 –http://www.telegraph.co.uk/) that has occurred without any warning.

Thus, we propose a qualitative graph (Fig. 17.10) which tries to explain the evolution of mortality rate taking into account the type of structure and damage grade. To become of quantitative value, this proposal requires an analysis of more data in a homogenised way; and this data collection can only be done by investigation immediately after the event.

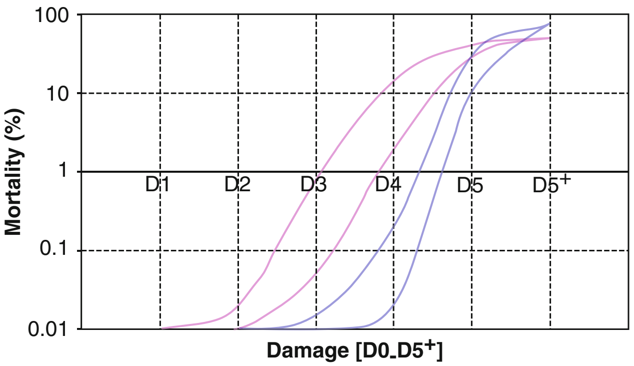


Fig. 17.10 Proposed qualitative relationships between building damage grade (masonry – magenta; reinforced concrete – blue) and percentage of deaths

17.4 Conclusions

Casualty estimation is a very uncertain issue; it depends on a variety of parameters among which are the damage level and the occupancy rate at the time of the event. It also depends on the population's behaviour during and after the event especially to avoid the consequences of aftershocks. It is very important to be aware of these parameters for a better understanding of the behaviour of the population prior to an earthquake, carefully separating the different variables affecting the process. We cannot be satisfied with the results of present models. In this chapter several topics have been discussed and some suggestions have been made which it is hoped may lead to an improvement of casualty estimation models for future application.

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Web links:

http://www.comuni-italiani.it/ (consulted in May 2009)

http://racconta.kataweb.it/terremotoabruzzo/index.php (consulted in April 2009)

http://portale.ingv.it/real-time-monitoring/quest/lavori-recenti-sull-area-aquilano-teramana/2009-08-06.8806198646/download (consulted in October 2009)

http://www.protezionecivile.it/ Emergenza sismica in Abruzzo, 6 Aprile 2009. Assistenza alla popolazione. Aggiornamento ore 08.00 del 21-5-2009 (consulted in May 2009)

http://www.telegraph.co.uk/news/picturegalleries/worldnews/6987916/Haiti-earthquake-aerial-and-satellite-photos-of-Port-au-Prince-from-the-air-and-space.html (consulted 17 January 2010)

Chapter 18
Trends in the Casualty Ratio of Injured to Fatalities in Earthquakes

M. Wyss and G. Trendafiloski

Abstract The worldwide ratio of injured to fatalities in earthquakes, $R = \text{Inj/Fat}$, has increased over time. This shows that it is more likely by approximately a factor of 2 that a person survives an earthquake today than 50 years ago. However, any meaningful analysis of R requires (as a minimum) separation by type of country and by location of epicentres (land or offshore). R in earthquakes beneath land is typically half of that for events offshore. R in the industrialised world is about two to three times larger than in the developing world. The countries that have made the greatest progress in protecting their population are Japan and China. Countries where R has not increased with time include Iran, Turkey, and Greece. The basic trends are clear, but the data sets for some individual countries are too small for the averages to be considered firm. We propose to use R to adjust the casualty matrices for estimation of human losses due to earthquakes worldwide.

18.1 Introduction

Estimating human losses due to earthquakes in real-time and scenario mode is becoming more necessary as the world population increases dramatically. Methods and data sets for estimating losses have been improving. However, they are still rudimentary for many parts of the world and for many aspects of the problem. We think that progress can be made in estimating human losses in earthquakes by modifying collapse rates of buildings and casualty matrices such that the historically observed casualty ratio, $R = \text{Injured/Fatalities}$, is correctly calculated. There are approximately 300 earthquakes since 1950 for which the numbers of fatalities and injured is known, after excluding events for which the data are not useful for one of the reasons given below. We are in the process of preparing and analysing this data set in such a way that we can use it for calibrating casualty matrices for earthquakes in developing countries.

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18.2 Properties of the Casualty Ratio

We propose R as a measure of change in resistance of buildings to shaking because it does not depend directly on the magnitude of earthquakes but on the intensity, regardless of the magnitude that generated it. Parameters such as fraction of the world population killed or injured depend on the distribution of magnitude of earthquakes in populated areas as a function of time. In the latter datasets, large earthquakes that kill tens- or hundreds of thousands dominate some periods, whereas in the data set on R unusually large numbers of fatalities are balanced by large numbers of injured.

R can be smaller than 1 in settlements built with adobe or mudstone walls and heavy roofs because the number of people killed at high intensities can be larger than those injured. The opposite extreme, namely R reaching infinity (zero fatalities, but numerous injured) is encountered at the same intensity, if buildings are built such that they do not collapse. In this case, there are no fatalities, but injuries may still occur, due to nonstructural damage, such as broken glass, falling furniture, and partial structural damage.

In a society that has advanced from a state of vulnerability to better earthquake resistance over the years, R should increase, from values between 1 and 3, observed around the year 1900 (Table 18.1), to larger values. However, to analyze R in detail, we have to consider the properties of this parameter to group the earthquakes studied in a way to reduce heterogeneity of underlying conditions. In the following, we list conditions that modify R and that should be considered in its analysis.

1. Construction material, practice, and building codes in industrialised and developing countries are different. Thus, the effect of earthquakes on people, as measured by R, is so different that the data should not be mixed. R in industrialised countries is two to three times larger than in developing countries (Table 18.1, Fig. 18.1).

Table 18.1 Medians of the casualty ratio in earthquakes with minimum magnitudes of 6 and minimum numbers of injured or fatalities of 40. The numbers of observations are given in parentheses. Except for the top row, only shallow earthquakes onshore are used

Dataset	500–1899	1900–1949	1950–1969	1970–1985	1986–2008
World	**1.2** (72)	**2.8** (121)	**5.4** (139)	**4.3** (104)	**6.9** (190)
Onshore and shallow only					
Developing (not China)			**3.0** (45)	**3.2** (23)	**4.8** (53)
Industrialised			**8.8** (44)		**11.2** (20)
China			**2.5** (35)		**12.8** (35)
Japan			**6.6** (21)		**47.5** (6)
Latin America				**2.6** (12)	**8.0** (11)
Turkey, Iran			**2.6** (19)		**3.6** (26)
Greece			**18.6** (9)		**11.2** (5)
Italy			**3.9** (8)		**7.0** (5)

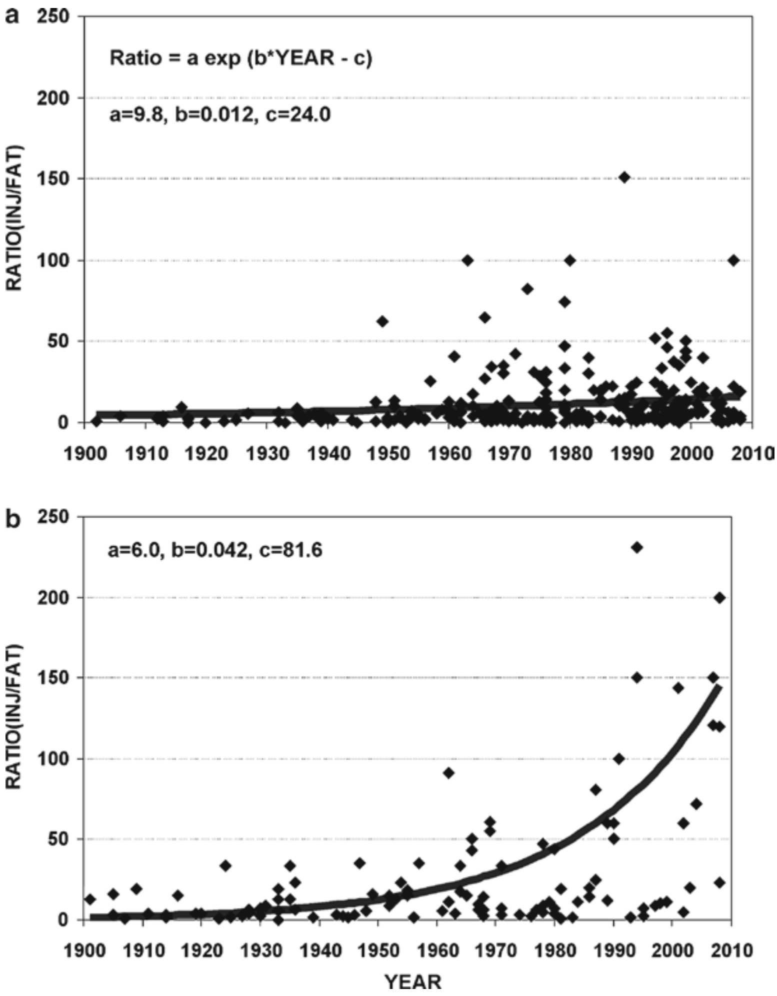

Fig. 18.1 Casualty ratio in earthquakes as a function of time, (**a**) in developing and (**b**) in industrialised countries. The ratio has been increasing during the last several decades, indicating that the percentage of people dying in earthquakes is decreasing in the developing as well as in the industrialised world. The data are from Utsu (2002) completed for recent years from the list of significant earthquakes posted by the US Geological Survey on http://neic.usgs.gov/neis/epic/. To reduce spurious data, events with $M<6$, and those with both Fat and $Inj<40$, and earthquakes located offshore and deeper than 50 km were excluded. Coefficients of the exponential fit through the data are shown in the *upper left*

2. R also depends on Intensity (I). In a settlement that experiences low shaking, there will be no fatalities, but injuries do occur. Earthquakes that produce only low intensities are small magnitude (M) events and those located far offshore. These types of earthquakes produce anomalously high R-values and cannot be used to estimate building quality.

3. The building stock in large cities differs from that in rural settlements. Large cities contain engineered structures and many five to ten storey apartment buildings, types of buildings that do not exist in rural settlements. Thus, R depends on the type of settlements affected by a given earthquake. Some quakes are located far from any large city, others happen beneath one. Such earthquakes generate different R-values, even in the same country with uniform construction practices.
4. The numbers of fatalities and injured in a single earthquake is composed of contributions by numerous to thousands of settlements. Some are located close to the epicentre and experience high intensities. Those far away register only low intensities, and some environments are urban, others rural. R-values differ, depending on the composition of settlements affected.

18.3 Data

To calculate the values of R, we used Utsu's (2002) catalogue of deadly earthquakes worldwide, supplemented with 29 events for 2005 through 2008 from the list of significant earthquakes maintained by the US Geological Survey. To reduce the heterogeneity of the data and to enhance their quality, we took the following measures. (a) We separated industrialised and developing countries, and, where possible, analysed data from single and neighbouring countries. (b) We deleted events for which neither of the parameters Fat and Inj is larger or equal to 40, to avoid spurious R-values. (c) To eliminate anomalously high R-values due to earthquakes that produced only low intensities, we deleted small earthquakes ($4.2 < M < 6.0$), offshore earthquakes, and events with depth > 50 km. An additional necessity for eliminating small magnitude events is that their percentage in the world data set increases with time, due to improving communication capabilities.

Casualties due to ancillary effects should be excluded in our study because we are aiming at understanding and modelling the behaviour of residential and office buildings in strong shaking. In recent earthquakes where the numbers of fatalities attributed to tsunamis and landslides are given, we subtract these and retain the event with its casualty numbers related to building damage. In the few cases where fatalities in old churches are known, we also subtract them from the total numbers. Earthquakes for which it is known that a large fraction of the fatalities were due to a tsunami, but the percentage is not known, are excluded from the study.

The uncertainties that can affect the number of reported fatalities and injured include the following: Casualties from remote areas may not be included. Casualties due to landslides, tsunamis, and other ancillary effects may be included. Local officials may purposely modify the reports. Reports of injured suffer in addition from the fact that the minimum level of injuries to be counted is not defined. For this reason it may be more appropriate to speak of 'patients', meaning those people that seek help in a healthcare facility, and are therefore included in statistical counts. Given these uncertainties, we will rely on averaging many events to define relative levels of R in different data sets.

18.4 The Casualty Ratio as a Function of Time and Space

In a crude first approximation of considering the data for the entire world, we have sufficient events to estimate R in five periods (Table 18.1, top row), finding that this parameter has increased. To decide the periods of data aggregation we considered building construction practice worldwide, in particular those having seismic design codes with various levels. R increases as a function of time in both the developing and the industrialised world (bold R value in Table 18.1). However, R is about twice as large in the industrialised world as in developing countries (Table 18.1).

China and Japan are the countries with the largest incidences of fatal earthquakes. In both of them, strong progress has been made in decreasing the percentage of fatalities, as demonstrated by five- and 11-fold increases of R in China and Japan, respectively (Table 18.1). In Latin America the increase is about twofold. In Iran and Turkey, neighboring countries for which we combined the data, there is no change with time (Table 18.1).

Bilham (2004, 2009) has shown that the fraction of the world population killed by earthquakes has decreased with time. Figure 18.2 shows that the fraction of people injured by earthquakes is increasing. Together with our result that R increases the value shown in bold in Table 18.1, we conclude that improved building practice has moved victims of earthquakes from the fatality to the injured category, more than moving people from the injured to the unscathed category.

The results we present here can only be considered as approximate because many uncertainties exist in the data. First, the reported numbers of fatalities and injured are often only estimated. In addition, it is generally not known what percentages of lightly injured persons are included in each count. Also, there are several factors other than building quality that can influence R.

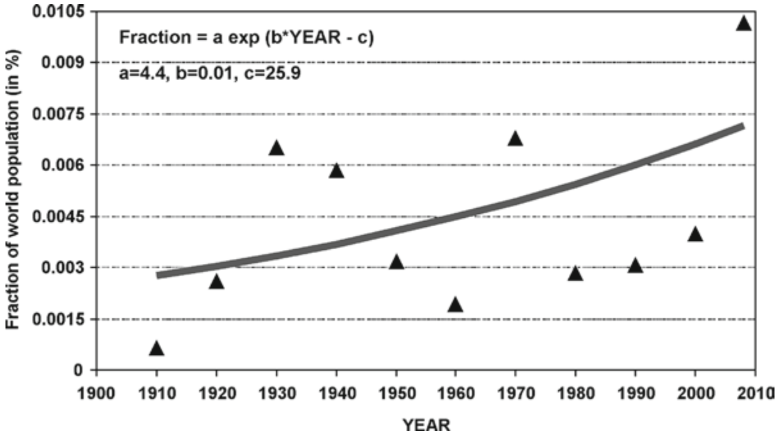

Fig. 18.2 Fraction of the world population injured by earthquakes as a function of decades and exponential regression model fitting the observations

Using the standard deviate Z-test to estimate the statistical significance of the differences between averages with more than 30 samples, we find significances exceeding 99% for industrialised versus developing nations, and for industrialised before versus after 1970. The differences of offshore versus land samples of both the industrialised and developing nations score above the 95%, but below the 99% levels. Differences between some of the smaller samples in Table 18.1 score below the 90% significance level, but we present their medians nevertheless because the beginning and ending of the selected periods are times when new building codes came into effect in several countries.

18.5 Estimation of Human Losses Worldwide, Using the Casualty Ratio

Currently, we are constructing our second-generation loss estimation tool QLARM (earthQuake Loss Assessment for Response and Mitigation) and upgrading the input database to be used in real-time and scenario mode (Trendafiloski et al. 2009a). To improve our loss estimates, in particular those of injured, we propose to fit the ratio injured to fatalities by adjusting the existing casualty matrices.

We evaluated the usefulness of the HAZUS and ATC-13 casualty matrices because they are frequently applied worldwide, although they were intended for use in the USA only. We believe that casualty matrices must be constructed separately for regions with similar building properties. Such regions may include several neighbouring countries, or sub-regions of large and complex countries, like India and China. We used observations from Iran as an example in Fig. 18.3 because

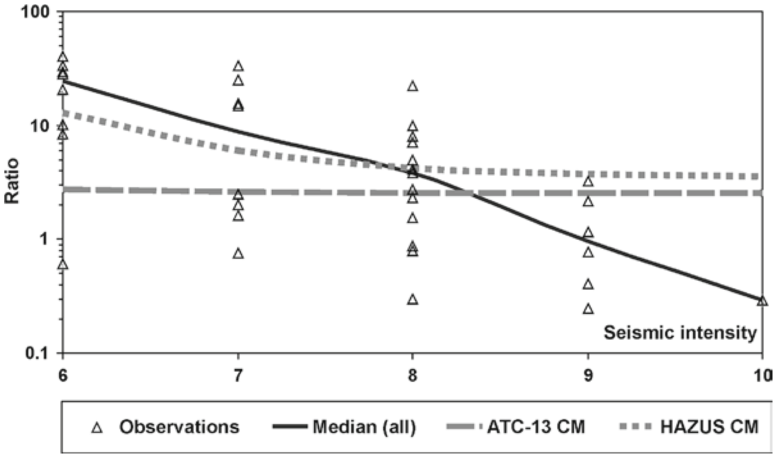

Fig. 18.3 Comparison of the observed and calculated ratios for Iran for different seismic intensities with HAZUS and ATC-13 casualty matrices

there are 37 relatively recent earthquakes with data available (Utsu 2002; Berberian 2005). The city model we assumed to calculate losses is that of building conditions in medium-size settlements in Iran (population 3,000–30,000).

When calculated by the ATC-13 casualty matrices, the ratio R for Iran has a constant value of 2–3 for all intensities, which does not fit the observations in Fig. 18.3. The ratio calculated by use of HAZUS matrices fits the observations in the intensity range of 7.5–8.5, but not outside of it. Thus, we propose to adjust the casualty matrices in QLARM to account for the observed ratio as a function of the seismic intensity (Trendafiloski et al. 2009a). This is important for developing countries in Southern Asia where very low values of R are observed ($R<1$) for seismic intensities larger than 9.

18.6 Discussion and Conclusions

The uncertainties in reported fatalities and even more so in injured are considerable for many earthquakes. This is especially true for early times and for countries applying media control. Some case histories of outstanding reporting errors have been documented by Bilham (2009). Nevertheless, we have to work with the available official information. We must delete data from small earthquakes, offshore and deep events. We must use averages, and we should group data from countries with similar building types. Provided we take these precautions, and provided we keep in mind that only our most basic results are firm, we can reach some conclusions.

The most basic, robust observation is that a decrease of fatalities compared to injured in earthquakes has been achieved globally (Table 18.1, Fig. 18.1). This supports the observation by Bilham (2004, 2009) that fatalities in earthquakes have not kept pace with the increase of the population of the planet with time. Spence (2007) shows the dramatic loss of life in the years after 2000 due to earthquakes in a wide sense, including the approximately 280,000 fatalities caused by the tsunami in the Indian ocean in December 2004. Being concerned with the resistance of buildings to strong shaking, we have excluded deaths caused by tsunamis. Therefore, we interpret the combination of Bilham's results (the percentage of the population killed by earthquakes decreases with time) and our results (increasing R, and increasing percentage of injured) as an indication of improved building practices.

We propose to use R as an indicator of building quality because the worldwide statistics have shown that about 75% of the fatalities attributed to earthquakes were caused by the collapse of buildings that were not adequately designed for earthquake resistance, were built with inadequate materials or were poorly constructed (Noji 1997a). However, the progress in reducing fatalities is uneven. Among the countries and regions where there were enough data to estimate the change in R, Japan is leading in improving the safety of its citizens (Table 18.1). China has also made great progress and seems to approach standards of the industrialised world, although the data in some cases may not be among the most reliable. Progress in Latin America appears to have been substantial, but earthquake safety still lags behind that in the industrialised world. Finally, it appears that not much progress has been made in Greece, Turkey and Iran, although the number of observations in a single country is too small to draw firm conclusions.

Improving the quality of the built environment is not an easy task and it requires resources. Building codes are not a panacea for all problems and mainly result in earthquake-resistant buildings rather than earthquake-proof buildings. Structures built according to code should resist minor earthquakes without damage, resist moderate earthquakes without significant structural damage, and resist severe earthquakes without collapse. The goal is to protect building occupants by preventing collapse, thus allowing evacuation of injured. Codes only recently began to address mitigation of nonstructural hazards in buildings, which might cause injuries.

When governments increase the requirements in building codes only new buildings are affected, but most people continue to live in old structures that are equivalent to death traps in some countries. Also, resources and the political will to enforce building codes by inspections on construction sites may be lacking in some countries. The established levels of earthquake-resistant design and construction of buildings are strongly related to a country's GDP level and they change over time. The level of acceptable seismic risk should be a realistic balance between building design requirements and a country's economic power.

There are countries where the record does not contain enough fatal events to estimate R, but where the potential for earthquake disasters exists. In countries like the USA and Canada, this poses no problem because awareness of the earthquake risk is high and efforts are made to protect the population. In other earthquake prone countries, where building materials and construction styles are poor, it would be desirable to quantify the danger the population faces by calculating parameters quantifying the earthquake risk, including the ratio R. Countries where this condition exists, but not enough recent deadly earthquakes have been registered for detailed analyses, include India, Pakistan, Nepal, and Afghanistan. We believe that India with its large risk potential is especially vulnerable (Wyss 2005).

To improve the casualty estimates, in particular the number of injured in developing countries, we propose to consider the casualty ratio R to adjust casualty matrices pertinent to vulnerability classes of buildings with low resistance, such as A, B and C according to the European macroseismic scale.

We conclude that overall the engineering efforts to protect the population from dying in earthquakes has brought fruit.

Acknowledgments This report was prepared with the support of the Japan Tobacco International Foundation, based in Switzerland, and the Swiss Agency for Development and Cooperation, but does not necessarily reflect the opinion of these parties.

Chapter 19
Study of Damage to the Human Body Caused by Earthquakes: Development of a Mannequin for Thoracic Compression Experiments and Cyber Mannequin Using the Finite Element Method

E. Ikuta and M. Miyano

Abstract The direct casualties of the 1995 Great Hanshin Earthquake disaster included 5,502 dead and 41,527 were injured. The death rate among victims in collapsed buildings was purported to be as high as 90%. However, there is no way of knowing how the victims died or were wounded, except from autopsies and interviewing the bereaved. In order to realistically model casualties in loss estimations, engineers need knowledge on causes of injuries and deaths and how and where they occurred, whether it was due to structural collapses or non-structural failures. As part of this investigation, the group at Osaka City University generated a database of casualties and obtained data from the Kobe earthquake to support the development of a prototype mannequin which is based on a crush test mannequin for the automobile; this was used to measure human body damage due to a simulated collapse of building as well as toppled furniture. This mannequin will also later be used in life-size structure fracture tests on a shaking table. In addition, a cyber mannequin has been developed to assess human body damage using the finite element method. The cyber mannequin has been developed because fracture testing using the mannequin is extremely costly and therefore rare and the 3-D simulation can be used to estimate and calibrate the impact on the human body.

19.1 Database of Casualties due to the 1995 Great Hanshin Earthquake

19.1.1 Records of the Casualties in the 1995 Great Earthquake

The number of direct victims (not including deaths and injuries due to fires) is 5,502 dead and 41,527 wounded. Autopsies were carried out by the coroner of the Hyogo Prefecture of all those who died in the earthquake. In addition, the task force for

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examination of early emergency treatment gathered medical records of hospitalised patients for the purpose of investigation of crush syndrome.

However, these records only consist of casualty numbers and not causes of deaths and hospitalisation. Therefore, the group integrated records of building damage to the related medical records and built two categories (deaths, serious injury) in the "Comprehensive Casualties Database". Items included in each of these categories are "age, sex distinction, contents of hazard, part of body struck, object that caused casualty, building damage, building structure, etc." (Nishimura et al. 1997; Sugimoto 1996; Ikuta et al. 2001) (Table 19.1).

19.1.2 Deaths

Using our database of deaths and structural damage caused by the Great Hanshin Earthquake, the following investigations were conducted. Valid data were obtained from 4,956 cases. Figure 19.1 shows that the most common direct cause of death was compression (suffocation) ($n=3,156$, 64%), followed by trauma (bone fracture) ($n=862$, 17%), and burns ($n=451$, 9%). More specifically, the actual cause of death was compression in 1,339 people, nasal obstruction in 60 people, nasal compression in 21 people, and airway obstruction in 11 people. Hence, of the 1,665 people whose causes of death were known, 1,431 people (86%) died of suffocation due to compression or obstruction.

Table 19.1 Total number taken from the compiled comprehensive databases

	Total Number
Dead	4,956
Seriously injured	1,349

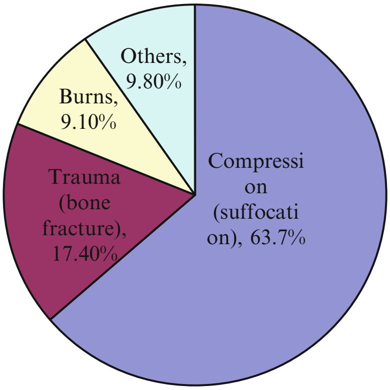


Fig. 19.1 Distribution of direct causes of death

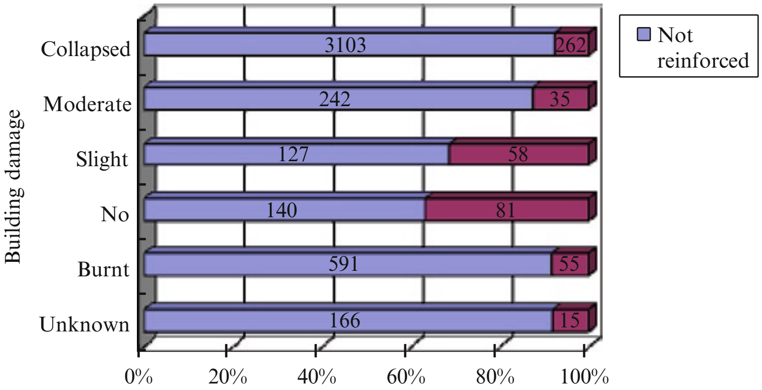


Fig. 19.2 Relationship between structural damage and type among deceased cases ($N=4,875$)

Furthermore, the object that directly caused death was clear for 3,071 people: building materials were responsible for 3,038 deaths and toppling furniture for 33 deaths. In other words, most deaths are attributable to structural damage, whilst toppled furniture only accounted for 1% of all deaths.

The comprehensive database used in the present study includes data about the severity of structural damage and the type of structures that sustained damage. Figure 19.2 shows the relationship of human casualties to structural damage and building type. Of the 4,956 people in the sample, 4,369 were in buildings that were not reinforced (mainly wooden buildings), and only 506 people were in buildings that were made of reinforced concrete or steel. These results suggest that most people died in wooden buildings. Furthermore, as shown in Fig. 19.2, except for injuries caused by burning wooden buildings, the overwhelming majority of victims died in completely collapsed or severely damaged buildings.

In order to use the computer to simulate human casualties in earthquakes, as discussed later, it is necessary to clarify the common areas of lethal injury. Therefore, the group utilised the above-mentioned database to analyse the relationship between the location of injury and the length of time until death. The results showed that injuries to the chest were the causes of death in 693 people, while injuries to the chest/abdomen were the cause of death in 421 people. These two areas accounted for 67% of the total. In addition, 94% (1,048 people) died due to compression, and it is our belief that most of these people were suffocated to death.

The common mode of death resulting from the Great Hanshin Earthquake was as follows: the earthquake caused wooden buildings to collapse, thus trapping people with their chests compressed by building materials, resulting in suffocation within a short period of time (less than 15 min). In the present study, “total collapse” refers to the destruction of the first and/or second floor of buildings, eliminating all living space (Fig. 19.3).

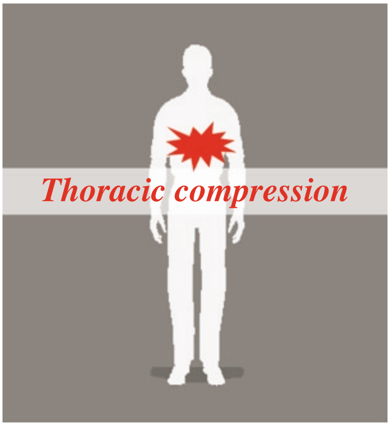


Fig. 19.3 Principal struck part (deaths)

19.1.3 Severe Injuries

The above-mentioned database includes the results of a study on people with severe injuries. This study investigated the relationship between severe injury and structural damage, and the results are summarised in the present study in order to compare deaths and severe injuries.

A total of 1,349 cases were studied. Building materials caused severe injuries in 428 people. Similarly, furniture caused severe injuries in 443 people. The most common form of injury was fracture ($n=750$, 56%), followed by contusion ($n=368$, 27%). These two forms of injuries accounted for 83% of the total. With regard to the relationship between injury type and injury-causing object, bone fracture was caused by building materials in 230 people, bone fracture was caused by toppled furniture in 264 people whilst contusion was caused by building materials in 137 people, and contusion was caused by furniture in 127 people.

Figure 19.4 shows the relationship between the severity of structural damage and the type of structure among the people with severe injuries. Whilst most of these people were injured when wooden buildings collapsed completely, some were injured in buildings that sustained relatively less damage (partial collapse or less). In reinforced buildings, people were injured even when the building sustained minor damage, and the greatest number of people ($n=121$) were injured in buildings that sustained no structural damage. In contrast to what was observed for lethal injuries, building materials and furniture caused similar numbers of severe injuries. It is evident that severe injuries can occur due to toppling furniture in buildings with minor structural damage.

In order to simulate human casualties in earthquakes as discussed later, it is necessary to clarify the main locations of injury among people with severe injury. The main areas of human injury were to the abdomen, legs and chest. This shows that earthquakes most often cause severe injuries when building materials (especially wooden buildings) or furniture cause fractures or contusions to the abdomen, legs or chest (Fig. 19.5).

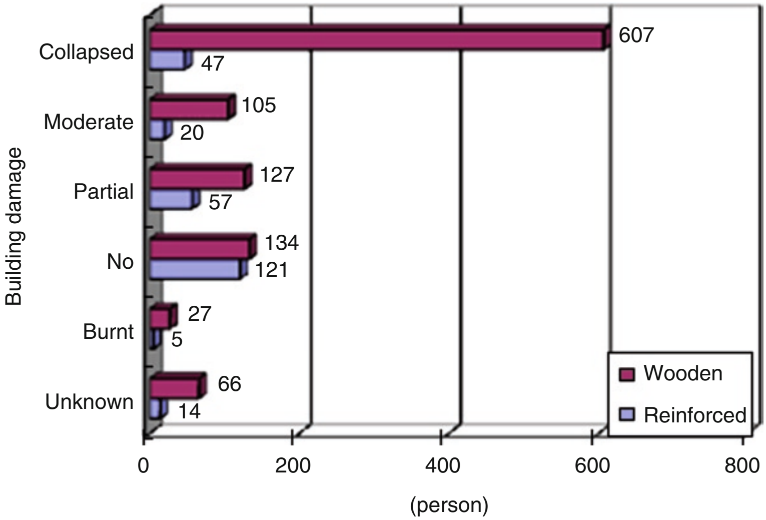


Fig. 19.4 Relationship between structural damage and building type among people with severe injuries ($N = 1{,}330$)

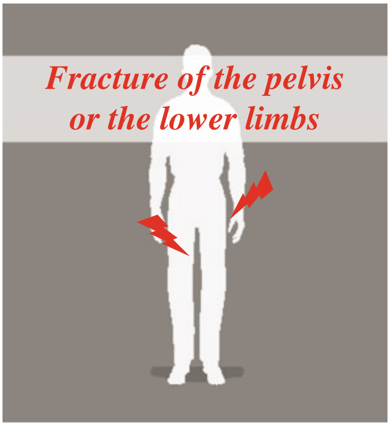


Fig. 19.5 Principal impacted parts of the body (severe injury)

19.2 Mannequin and Cyber Mannequin Development

19.2.1 Analysis of a Human Thoracic Compression Model by a CT Scanner

When analysing damage to the human body caused by structural destruction, death due to suffocation caused by thoracic compression was found to be an important reason. The objective of this study is to analyse deformation of the thorax and intrathoracic organs using a Computed Tomography (CT) scanner in an attempt to establish the necessary conditions for death due to suffocation caused by thoracic compression for use in computer simulation.

19.2.1.1 Method

The thoracic region of a healthy adult (26-year-old man) was compressed using a cylinder weighing 0, 10, 20 or 30 kg. The entire thoracic region in the state of maximum inspiratory and expiratory phases was analysed by a CT scanner (Toshiba Asteion-multi, Fig. 19.6). CT was performed under the following conditions: slice width 3 mm, tube voltage 120 KV, and tube current 120 mAs. Based on CT data, horizontal images were made at 1.5 mm intervals along the body axis, and three-dimensional images were reconstructed using an image processing workstation (Tera Recon Inc., Aquarius Workstation). Lung volume and thoracic cage diameter were measured. Lung volume was calculated by extracting the lungs from the reconstructed thorax by volume rendering. Thoracic cage diameter was measured by ascertaining the anteroposterior, transverse and longitudinal diameters on the thorax based on transverse, sagittal and coronal images.

Results

In order to maintain respiration, a certain level of tidal volume (lung capacity during inspiratory phase – lung capacity during expiratory phase) is needed. A comparison of reconstructed CT images during inspiratory and expiratory phases showed that changes in the lung volume were mostly attributable to the longitudinal movement of the diaphragm and anteroposterior changes in the thoracic cage diameter were due to elevation of the ribs (Figs. 19.7 and 19.8). Therefore, changes in each parameter caused by different levels of thoracic compression could be assessed.

Fig. 19.6 CT scanner experiment

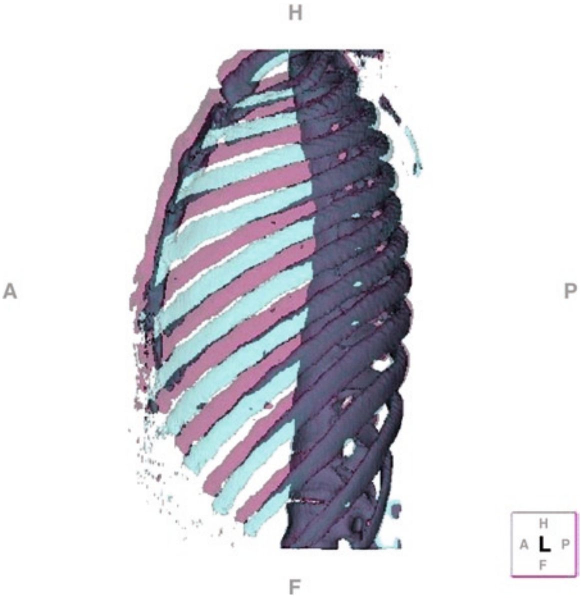


Fig. 19.7 Anteroposterior changes in the thoracic cage diameter

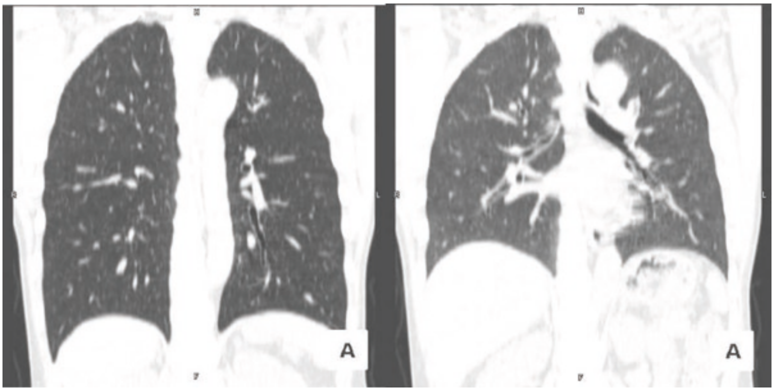


Fig. 19.8 Longitudinal movement of the diaphragm

1. *Changes in lung volume (Fig. 19.9a)*
   Both inspiratory and expiratory volumes decreased as the cylinder weight was increased from 0, 10 and 20 kg, but the vital capacity (the difference between inspiratory and expiratory volumes) was maintained at a comparable level. However, with a 30 kg compression load, the inspiratory volume was further decreased, thus causing the vital capacity to decrease.

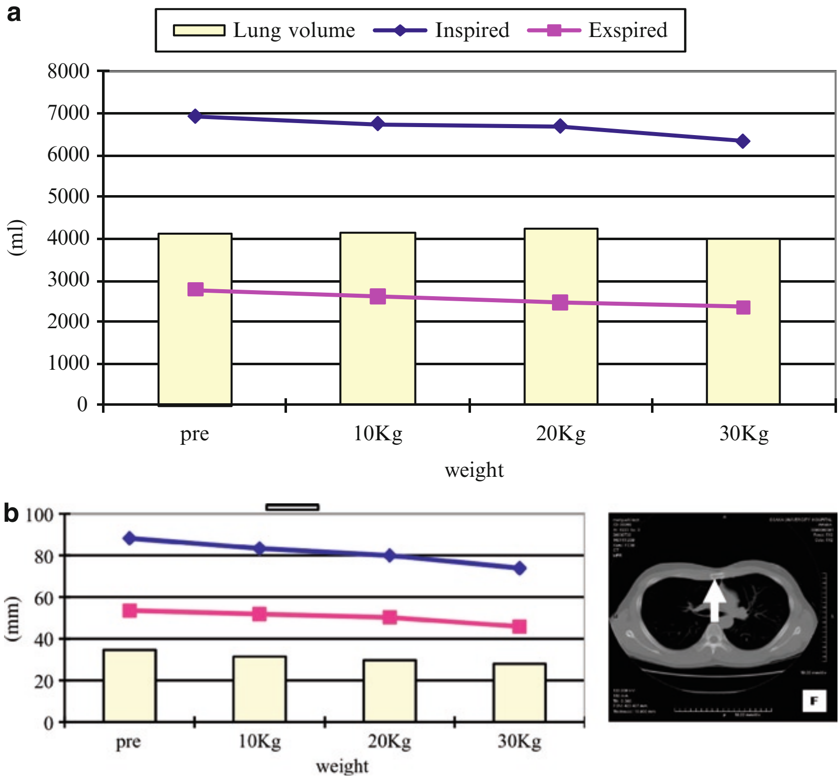


Fig. 19.9 (**a**) Changes in lung volume. (**b**) Changes in the anteroposterior diameter of the thorax

2. *Changes in the anteroposterior diameter of the thorax (Fig.* 19.9*b)*
   At the level of the tracheal bifurcation, the distance between the sternum and spine was measured. During inspiration and expiration, it was found that the greater the compression, the smaller the distance. In addition, with greater compression, the degree of change in the anteroposterior diameter of the thorax between inspiration and expiration became smaller.

   These findings suggest that the anteroposterior diameter of the thorax decreases with weight, thus lowering the vital capacity of the lungs.
3. *Changes in the distance from the pulmonary apex to diaphragm (Fig.* 19.10*a)*
   In this experiment, the distance between the pulmonary apex and diaphragm was measured. During inspiration and expiration, this distance decreased gradually with increasing compression. In addition, the degree of diaphragm movement associated with respiration decreased with increases of weight. Hence, it can be concluded that the restricted movements of the diaphragm due to thoracic compression also contribute to decreases in capacity of the lungs.

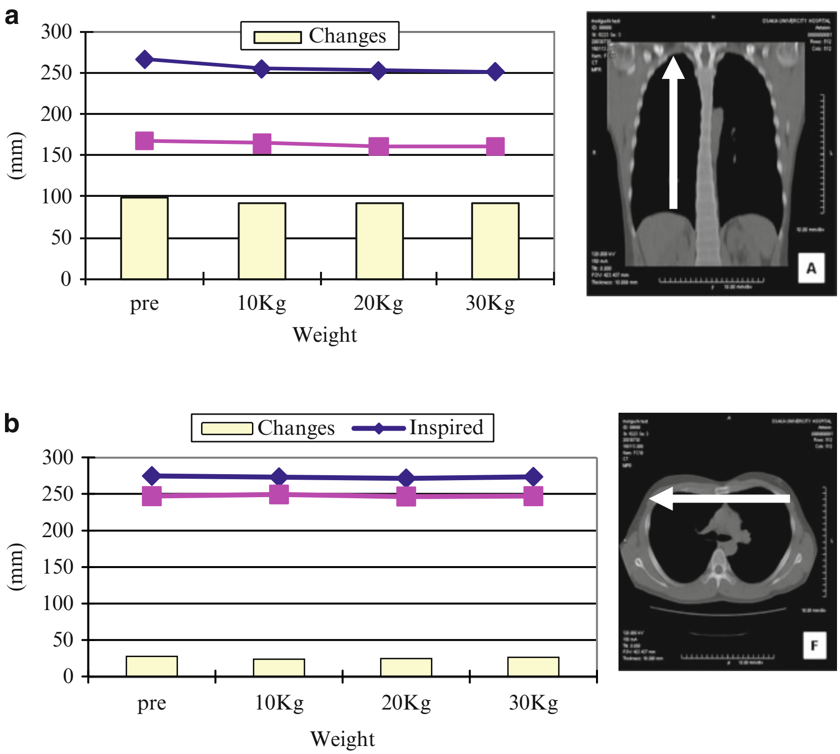


Fig. 19.10 (**a**) Changes in the distance from the pulmonary apex to diaphragm. (**b**) Changes in the transverse diameter of the thorax

4. *Changes in the transverse diameter of the thorax (Fig. 19.10b)*
   At the level of the tracheal bifurcation, the transverse diameter of the thorax was measured. The thoracic compression did not affect the transverse diameter of the thorax.

19.2.1.2 Issues to Consider in the Future

There are two ways of improving the present experiments. Firstly, the upper limit of thoracic compression in the present experiment system was 30 kg. Although 30 kg compression decreased the vital capacity, this capacity was still maintained; in other words, this level of compression was not sufficient to simulate death due to suffocation. In the future, the group plan to investigate a means of increasing compression and to ascertain the necessary conditions for death due to suffocation by studying more cases.

Secondly, 30 kg of compression did not bring about marked changes in the vena cava. If future experiments with increased levels of thoracic compression are found to affect the vena cava, then it is possible to consider this aspect when ascertaining the necessary conditions for death due to suffocation.

19.2.2 Mannequin Based on a Cardiopulmonary Resuscitation Training Mannequin

An experiment was developed using the mannequin "Resusci Anne SkillGuide" (a product made by KYOTO KAGAKU Co. Ltd.). As shown in Fig. 19.11 a mannequin used for CPR (cardio-pulmonary resuscitation) training was adapted and made into a suitable model for simulation of cardiac compression in a critical condition. This model is a marked improvement on a standard mannequin used in conventional experiments as the physiology of an average adult is taken into account.

A measurement sensor unit which evaluates the effects of cardiac compression was mounted on a sternal plate made of plastic in the thorax of Resusci Anne. A displacement meter, a product made by Kyowa Electronic Instruments Co. Ltd., was also attached to the sternal plate at bottom of the chest (Fig. 19.12). This study aims to standardise the method of measuring and quantifying thorax displacement as a parameter leading to death.

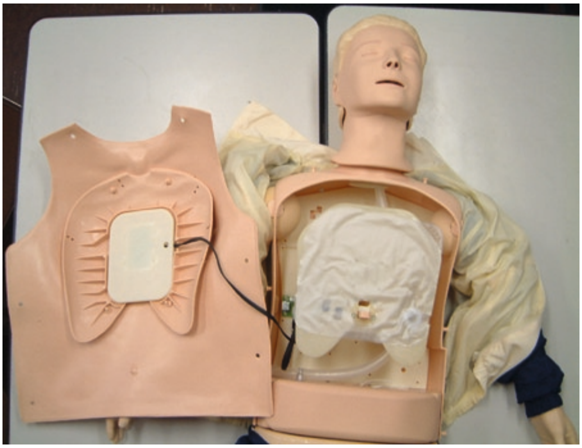


Fig. 19.11 Resusci Anne SkillGuide

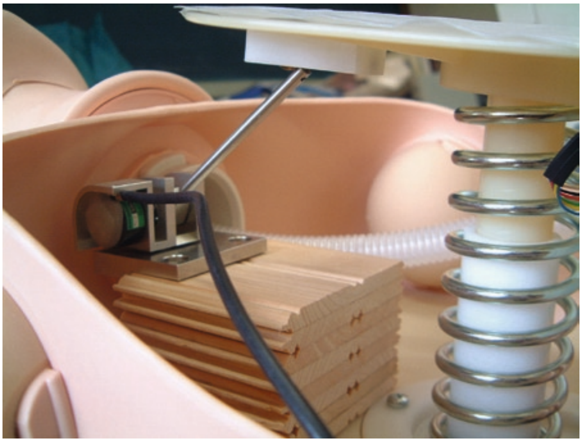


Fig. 19.12 Displacement meter in thorax

19.2.2.1 Static Loading Experiment to the Mannequin Chest

The study is used to simulate chest pressure causing death in an earthquake by compression. Therefore, a weight was loaded on the chest of the mannequin chest whilst lying on its back and the vertical displacement was measured. The displacement resulting by loading in 5 kg increments from 0 ~ 60 kg on the entire chest was measured as it lay on a concrete floor and recorded with a memory recorder analyser (a product made by Kyowa Electronic Instruments Co. Ltd.) at 2 kHz.

The vertical displacement Δy was estimated as:

$$\Delta y\left[mm\right] = L\left\{\sin\alpha - \sin\left(\alpha - \beta\right)\right\}$$

L: arm length of a displacement meter =92.49 [mm], α: initial angle [rad], β: angle under loadings [rad]

Figure 19.13 shows the average displacement at each loading increment on the mannequin.

Risk Evaluation

A previous study examining the risk of death by thoracic pressure is an experiment with mice by Furuya (1981). The mouse was pressed on the chest by a weight on a stand. According to this study, if the mouse was loaded with more than three times its weight on its chest, the mouse was in danger of dying. If the mouse had a load five times its weight on its chest, the mouse would die in a short space of time. Of course the experiment was not replicated to study the risk of death to humans.

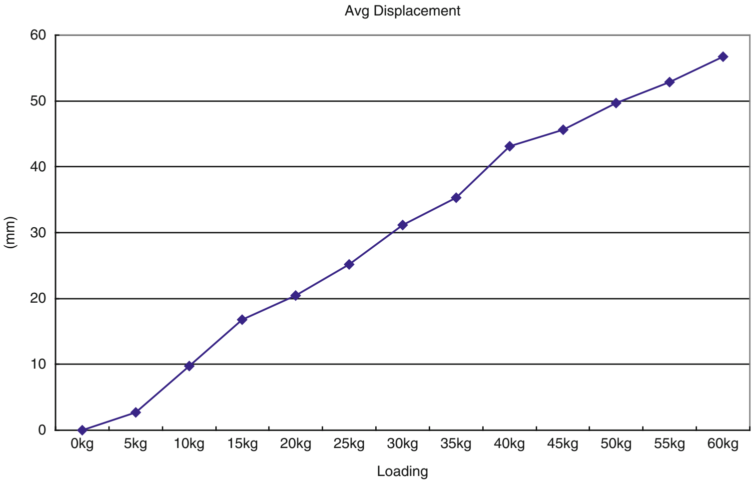


Fig. 19.13 Average displacement of chest

19.3 Cyber Mannequin Using Finite Element Method

19.3.1 Software

In this study, the 3-D finite element software LS-DYNA was used. LS-DYNA is a general-purpose program used for analysing nonlinear problems with explicit time integration based on the central difference method and spatial discretisation based on the finite element method. LS-DYNA can be used for a wide variety of problems, from dynamic analyses of shock and impact problems to quasi-static analyses of plastic forming (Miyano et al. 2003).

19.3.2 Model

Geometric shape data for a human thorax were firstly obtained from Digimation, Inc. The data were then converted to FME simulation format and split in order to reduce the simulation time (to half). The model meshing and element preparation were then carried out. The physical properties and various boundary conditions were set as shown in Fig. 19.14.

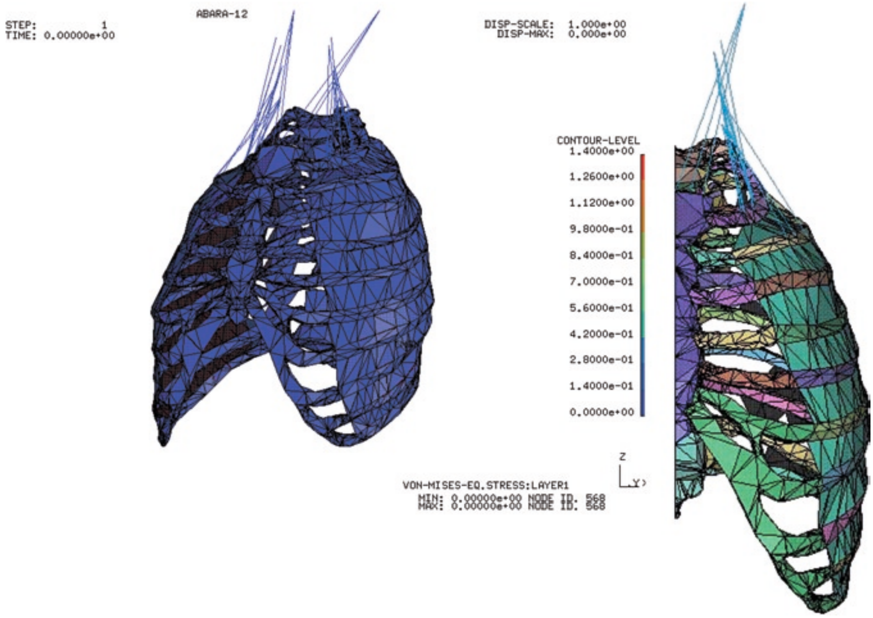
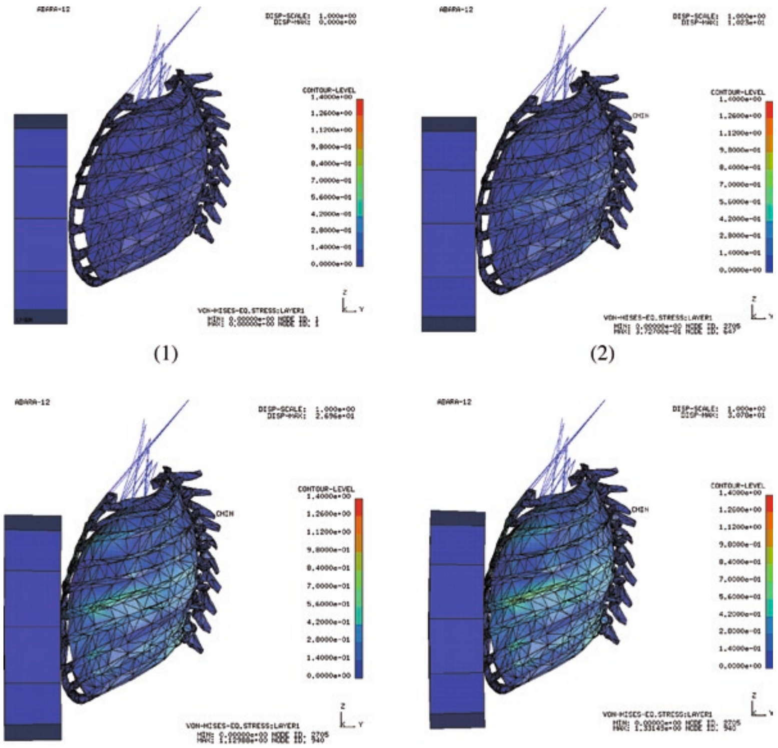


Fig. 19.14 Cyber mannequin (thorax)



(1) (2)

(3) (4)

Fig. 19.15 Animation of the simulation (30 kg)

19.3.3 Simulation

This simulation was conducted with the same conditions as the previous CT scanner experiments. The model lies horizontally with a weight placed on its thorax. Figure 19.15 shows the animation of this simulation with a 30 kg load.

19.4 Discussion

It was found that the behaviour of the thorax in the FEM simulation and the result from CT scanner experiments were very similar. When the thorax was compressed, the entire rib cage moved down with rotation as shown in Fig. 19.16. The displacement of the sternum was similar at the inspiratory phase and expiratory phase at each load: 0 kg, 10 kg, 20 kg, 30 kg (Fig. 19.17).

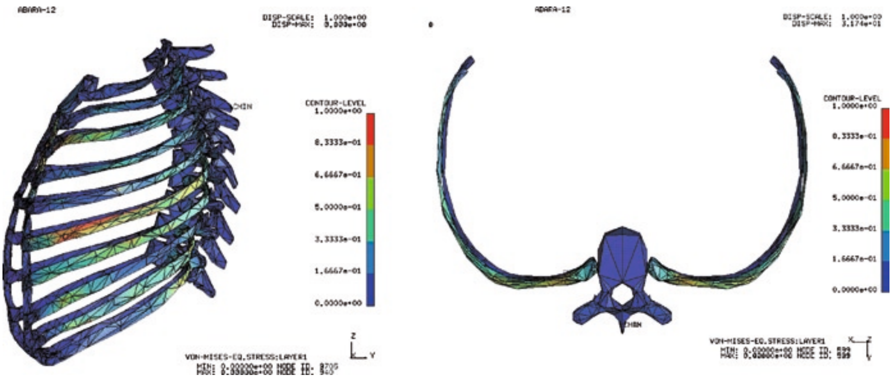


Fig. 19.16 Behaviour of the thorax when compressed (*Left*; left side, *Right*; 6th rib)

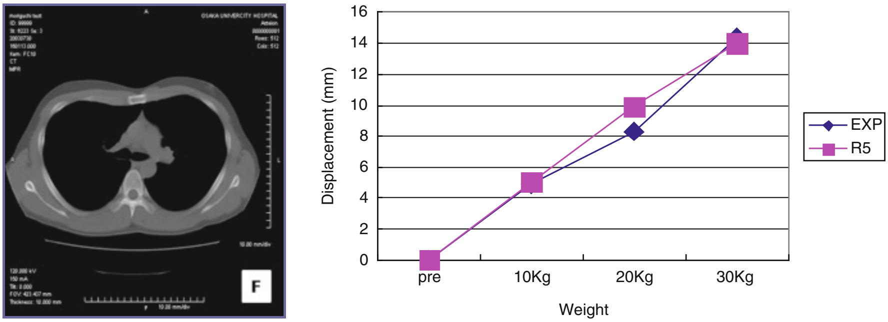


Fig. 19.17 Displacement of the sternum at each weight level

19.5 Conclusions

In this study, based on a comprehensive database collated with structural damage and human casualties caused by the Great Hanshin-Awaji Earthquake, the injury-causing objects, injury locations and activities during the earthquake were investigated. Based on these results, a typical mode of injury was recreated using LS-DYNA in order to investigate the suitability of the present numerical analysis of compression-generated injuries.

The results of the present study and future tasks are as follows:

1. One of the typical modes of death caused by the Great Hanshin-Awaji Earthquake was that people in totally collapsed wooden buildings died within a short period of time due to chest compression.
2. Building materials (particularly with wooden buildings) and furniture were the two main objects that caused severe injuries: bone fractures and contusions to the abdomen/lumbar region, legs or chest.

3. Mostly favourable findings were obtained by the LS-DYNA simulation of quasi-static problems, including death due to suffocation.
4. The results from the simulation of a compressed thoracic behaviour are in good agreement with CT scanner experiments. Therefore, this simulation reflects actual human body damage due to compression.

The development of finite element methods can significantly improve our understanding of injuries and deaths in earthquakes and will help engineers reduce casualties if examined in conjunction with investigations into building collapse mechanisms.

Chapter 20
A Different View on Human Vulnerability to Earthquakes: Lessons from Risk Perception Studies

T. Rossetto, H. Joffe, and C. Solberg

Abstract A large proportion of people the world over do nothing or very little to adjust to seismic hazards. Antecedents of seismic adjustment adoption rates relate to fundamental motivations to understand, to belong, to enhance a sense of self-worth, to trust and to control. These motivations are accommodated within socioeconomic and cultural constraints. Understanding such motivations and constraints forms a step in understanding how to facilitate mitigative actions. Through consideration of these issues, the characteristics that define groups less likely to adopt mitigative measures against earthquake hazards are tentatively identified. A UCL-based study that looks to enhance the state-of-the-art knowledge on socio-psychological factors affecting seismic adjustment rates is described. It explores the barriers to seismic adjustment in individuals and small groups in three different countries, and this paper presents some of its initial findings.

20.1 Overview of Past Studies on Earthquake Risk Perception

Following the terminology of previous authors we use the term *seismic adjustments* to refer to those behaviours that either (a) mitigate immediate risks of human and economic losses due to damage to the built environment (e.g. structural retrofitting),

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or (b) prepare for and increase chances of survival and efficient response and recovery in the aftermath of an earthquake (e.g. earthquake insurance, stockpiling of essential amenities) (e.g. see Turner et al. 1986; Mulilis and Lippa 1990; Lindell and Perry 2000; Spittal et al. 2006).

The definition of risk perception adopted in this paper is *"perception of the likelihood and consequence of a future adverse event"* (Adams 1995). Rather than use the term in the strict sense of psychology's psychometric tradition (see (Slovic 2000)), the notion of risk perception used here encompasses a range of factors. Seismic risk perceptions have been measured in a variety of ways, broadly encompassing cultural, cognitive and, to a lesser degree, affective risk dimensions (e.g. Mulilis 1995; Palm and Carroll 1998; Lindell and Perry 2006). In this section a very brief overview is presented of the main findings from studies of earthquake risk perception carried out and published to date. A more complete review of the literature in this field is provided in Solberg, Rossetto and Joffe (2010).

The aim of this overview is to highlight the psychological drivers of seismic adjustment behaviours on the part of individuals, which are gleaned primarily from psychological studies. It is argued, later in the paper, that some of these drivers might be considered to more effectively promote the adoption of seismic adjustment measures. This section is divided into five parts, representing the main categories of psychological drivers identified in past studies.

20.1.1 The Influence of Perceived Risk on Seismic Adjustment Behaviours

Believing that one is at risk is widely assumed to be correlated with seismic adjustment motivation, and indeed a number of studies have found a positive correlation between risk perception and seismic adjustment measures (e.g. Turner et al. 1986; Palm and Carroll 1998; Flynn et al. 1999; Lindell and Prater 2000). Later work has tended to weaken this assumption of a causal process leading from risk perception directly to seismic adjustment (e.g. Lindell and Prater 2002; Perry and Lindell 2008). Overall a small positive correlation is seen to exist between risk perception and seismic adjustment behaviours, suggesting a weak direct causal linkage (Palm and Carroll 1998; Kirschenbaum 2005).

In terms of demographic differences, females and minority groups generally judge themselves to be more at risk regarding earthquakes than men and majority groups, respectively (e.g. Dooley et al. 1992; Karanci and Aksit 1999; Paradise 2006; Spittal et al. 2008). The links between socioeconomic status (SES) and risk perception seem to be somewhat irregular. On the one hand studies have linked higher educational achievements of populations in moderately developed countries to higher risk perceptions (Rüstemli and Karanci 1999; Paradise 2006; Armas and Avram 2008). On the other hand higher income, education and homeownership rates have been linked to decreased risk judgments in US respondents (Farley 1998; Lindell and Prater 2000). Contrary to expectations, older people are less likely to see earthquakes as a risk (e.g. Dooley et al 1992; Farley

1998; Palm 1998; Rüstemli and Karanci 1999; Lai and Tao 2003; Heller et al. 2005). One possible explanation for this is that elderly people living in relatively secure social circumstances have survived more earthquakes than younger people, and that these experiences have made seismic risk seem less threatening.

20.1.2 The Influence of Community Orientation and Social Norms on Seismic Adjustment Behaviours

People's perceptions of earthquake risk and adjustment behaviours involve processes that are profoundly social. Seismic adjustment attitudes and decisions are shaped by what we believe other members of our communities and social groups think, feel and do regarding seismic risk. Corroborating this assumption, Mileti and Fitzpatrick (1992) reported that seismic adjustments increased when respondents observed other people adjusting. Farley (1998) showed that believing that one's neighbours were prepared predicted more adjustment, whereas the belief that neighbours did not know how to prepare led to less adjustment. We both seek out and are inadvertently exposed to prescriptive risk communications that seek to influence behaviour through relaying socially normative messages. Informal discussion of earthquake topics, attendance at community earthquake preparedness meetings and the presence of strong and long-lasting ties to the community were all significant predictors of adjustment in the Turner et al. (1986) surveys. Heller et al. (2005) also found that in families where helping behaviour was common-place, higher levels of hazard-related discussion predicted adoption of seismic mitigation adjustments. Hence a sense of belonging to a community, linked with good communication processes in the family and among neighbours, friends and colleagues, may have an impact on risk adjustment.

People often deal with substantive uncertainty by turning to experts, peer groups and mass media for information and advice on how to deal with societal risks. Doing this ensures not only that one is exposed to expert risk reduction advice, but also ensures that our risk attitudes, norms and behaviours are in line with socio-cultural expectations. By attending to prescriptive messages we maintain a sense of understanding, belonging and control in relation to our social and material environments (Keltner et al. 2003).

20.1.3 The Influence of Perceived Trust on Seismic Adjustment Behaviours

As noted in the above section, seismic adjustment behaviour is partially determined by attitudes and norms that arise from in-group and inter-group dynamics. Slovic (2000) argues that a lack of trust between risk management authorities on one side and the non-professional public on the other can lead to controversy, divisiveness and ultimately powerful barriers to the enhancement of individual and societal resilience. Trust can be defined as the belief that an agent is competent and skilful at achieving a particular goal. Using such a definition, Paton (2088, see also Johnston et al. 2003) argues that trust is a crucial factor that underpins seismic adjustment adoption. According to Paton, when hazard characteristics and hazard adjustments are relatively unfamiliar to the general public, trust in risk managers' competence will motivate people to adopt adjustments. Conversely, distrust will lower adjustment motivations.

Corruption in the engineering and construction industries as well as the institutions that regulate these has been found to correlate strongly with injuries and deaths from seismic hazards (Escaleras et al. 2007). Corruption, the betrayal of communal trust and transgression of individual rights, elicits emotions of disgust and anger, with the primary behavioural corollary being avoidance of and aversion to the disgust-eliciting objects (Rozin et al. 1999). Green's (2008) fieldwork among gecekondu (quasi-legal) land squatters in Istanbul, for example, reveals the consequences that corruption has for seismic adjustment: The gecekondu perceived the Turkish construction industry, engineers and regulatory bodies as corrupt and therefore distrusted them. As Green shows, among Turkish land squatters this led to increased reliance on and valorisation of vernacular construction knowledge and practices, which differ significantly from officially sanctioned best practices. Hence, as a result of distrust, as well as financial constraints leading to utilisation of sub-standard materials and construction practices, Green estimates that Istanbul's extensive self-built, informal housing stock increases the vulnerability of its citizens.

Much more work is needed to clarify the roles of trust and distrust in driving earthquake adjustments, especially since the evaluations, effects, and behaviours that cause (dis-)trust seem to be culturally as well as individually variable (see Rozin et al. 1999). However, it seems that high levels of trust in the providers of information on risk and mitigation measures enhance seismic adjustment rates, whilst lack of trust hampers them.

20.1.4 The Influence of Sense of Responsibility on Seismic Adjustment Behaviours

Industrialised societies rely on a division of labour for their reliability, efficiency and resilience. We all perform a variety of roles in accordance with societal norms. Thus we are all subject to differing kinds of expectations concerning who and what we have a responsibility to protect and care for. The proposed causal chain leading from risk perception to increased seismic adjustment motivation is at least partially contingent on the presence of social, cultural, economic and political norms stating that the individual or the household should have some responsibility for seismic adjustments (Mulilis 1995; Lindell and Whitney 2000). Japanese respondents differed in responsibility attributions relative to Californian respondents in Palm and Carroll's surveys (Palm and Carroll 1998): the authors argue that Japan's cultural emphases on social interdependence and reliance on authorities led them to ascribe more adjustment responsibility to governments and experts than did Californians. That this had consequences for household adjustment seems possible from their findings that while the Japanese had stronger risk perceptions, they made fewer adjustments than their US counterparts. As Mulilis (Mulilis 1995) argues, individuals low in personal responsibility for preparation have no strong personal connection to the behavior . US surveys show that length of tenure, homeownership and the presence of dependents in the household correlate positively with seismic adjustment rates. It seems plausible that these are factors that, at least in some societies, co-vary with perceived protection responsibility (Duval and Mulilis 1999; Turner et al. 1986).

20.1.5 The Influence of Fatalism and Control on Seismic Adjustment Behaviours

Disaster researchers have consistently found that many people have an attitude of fatalism towards disaster risk and risk reduction. Fatalism is defined as the perception that one cannot adequately protect oneself against adverse risk consequences, and that the locus of control over life events is external to oneself (McClure et al. 1999). Earthquake fatalism specifically implies the idea that damage is thought to be caused by the force of an earthquake alone rather than arising as the result of interactions between uncontrollable geophysical events and controllable features of the built environment, such as building design and construction practices (McClure et al. 2001). In general, fatalistic attitudes and feelings of helplessness lessen the motivational force of hazard warnings and weaken intentions to adopt seismic adjustments. Turner et al. (Turner et al. 1986) found that fatalism among their Californian survey participants was higher among members of an ethnic minority, but decreased as educational levels of participants went up. The relationship between fatalism and preparedness was, as expected, strongly negative. This has been corroborated in surveys from central USA and Iran (Farley 1998; Asgary and Willis 1997).

In a survey by Flynn et al. (1999) about half of their Portland, Oregon participants displayed fatalistic attitudes regarding seismic risk reduction, but a strong majority (74.8%) judged the city administration capable of mitigating seismic risk. Furthermore there was relatively strong support for city-led risk reduction actions targeting community emergency preparedness facilities and vulnerable or critical populations and structures. These findings lead us to believe that the notion of fatalism must also be extended to cover expectations of what one's community can do to manage risk. We might be unsure of our personal ability to lessen seismic risk, but still believe in the community's ability to mitigate risk, or at least believe that other institutions and organisations have the primary responsibility and capability to reduce our vulnerability. The recent finding that people who believe they have some control over their personal and socio-political life domains are more likely to adopt mitigative seismic adjustments (Spittal et al. 2008) strengthens this conclusion.

The mental models of seismic hazards held by lay people have profound consequences for their sense of control. Explanations that stress the uncontrollable causes of earthquakes lead people to lose faith in their ability to control the environment, and can often lead to an attitude of fatalism. Fatalism can be induced, for example, by mass media reports that do not stress accurate, rate-based information about why certain types of buildings collapse and others survive tremors. McClure and colleagues have shown that New Zealanders with mental hazard models that are relatively congruent with scientific knowledge show an increase in perceptions of control. Feelings of control increase both motivations to undertake seismic adjustments and actual adjustment rates (e.g. McClure et al. 2001).

20.2 Tentative New Perspectives on Human Vulnerability in Light of Existing Risk Perception Research

The overview of empirical studies from the earthquake risk perception field presented above demonstrates that there are a number of factors that contribute to the adoption of seismic adjustment measures. These relate to people's perception of seismic risk, sense of belonging in a community, sense of trust, sense of responsibility and sense of control. The studies identify some features (including socio-economic and demographic) that characterise groups with low levels of these factors, and which are less likely to adopt seismic adjustment measures. These are summarised in Table 20.1, which shows that people defined as less likely to adopt seismic adjustment measures can incorporate social groups generally thought of as powerful , such as men and majority groups. It is however emphasised that the majority of existing empirical studies come from the Western United States and New Zealand, and are few in number. The authors expect that there will be large variations in the socio-economic and demographic characteristics identifying groups with low risk perceptions in different locations (even within the US and NZ).

The explicit recognition within disaster risk reduction (DRR) activities that socio-psychological factors contribute to human vulnerability can improve the

Table 20.1 Factors affecting seismic adoption rates and the socio-economic and demographic characteristics of groups identified in past empirical studies to be associated with these factors

Vulnerability factor	Characteristics of communities associated with the factor
Low risk perception	Men and majority groups. Older generations. Experience of past earthquakes that have caused low levels of damage/loss.
Individualism	Low sense of belonging in a community and lack of communication processes.
Lack of trust	Distrust of information sources. High levels of societal corruption.
Low sense of responsibility	High number of renters. Displaced sense of responsibility (high reliance on authorities).
Low sense of control (fatalism)	Ethnic minorities. Low levels of education. Lack of scientifically valid knowledge which promotes belief in the effectiveness of mitigation.

effectiveness of these activities in increasing seismic adjustments in individuals and small groups. Such DRR activities might include:

- The design of educational material that provides information on seismic adjustments in a way that reduces fatalistic attitudes to earthquake losses.
- The choice of effective means of information dissemination (e.g. through sources that are seen to be responsible, trusted and culturally congruent with the audience).
- Targeting groups with low risk perception (e.g. men belonging to majority groups, who are also more likely to be able to afford such measures) for awareness raising and mitigation promotion campaigns
- Facilitating discussions on emergency planning in a community to increase not only community resilience, but also its members sense of belonging, worth, control, understanding and trust.

20.3 A New Study at UCL

The review of the psychological literature on seismic adjustment revealed that the studies covered a limited geographical area, did not generally incorporate comparisons between different cultures (but see Palm and Carroll 1998 for an exception) and contained methodological problems (see Solberg et al. 2009). Furthermore, most of the studies implicitly or explicitly endorse a theory of human action as fundamentally guided by conscious, reasoned decision-making on the basis of cost-benefit analyses of action alternatives. We argue that researchers need to emphasise that individual behaviour is also motivated by subconsciously as well as societally determined symbolic and emotional variables. These cannot always be easily studied by way of quantitative surveys and quasi-experimental methods (Joffe 1999). Therefore, in order to better understand the psychological drivers of seismic adjustment of individuals and households in different cultural settings the authors, with backgrounds in Earthquake Engineering and Psychology, initiated a collaborative project that has been funded by the Environmental and Physical Sciences Research Council (EPSRC) under the Challenging Engineering Grant Programme.

20.3.1 UCL Study Methodology

The project, which began in July 2007, involves carrying out in-depth qualitative interviews with 144 respondents in Seattle (USA) ($n=48$), Osaka (Japan) ($n=48$) and Izmir (Turkey) ($n=48$). These cities were selected as they are locations with high seismic hazard that have not been directly subjected to a highly damaging earthquake in the last 40 years. The in-depth interviews adopt a methodology developed by Joffe (2003) that allows free association of ideas in a systematic framework.

The interviews in Turkey and Japan were carried out in collaboration with Middle East Technical University and Kyoto University, respectively. Following the interview, the respondents were asked to fill in a questionnaire designed to collect information on factors contributing to the respondent's physical risk (e.g. information on where and what type of building they live in) as well as parameters collected in other risk perception studies, to allow comparisons to be made with past studies. Purposive sampling was used: the genders are equally represented in each country, and distributed equally across the six decades from 20 to 70. Additionally, half of the respondents (households) in each decade and gender group were earning above the national median income level, and half below.

To date, the final interviews have been carried out, fully translated and transcribed. They have not yet been fully analysed by the authors and the results will therefore be reported at a later stage. We have however analysed some of the data arising from quantitative parts of the survey (the questionnaire) and present these results here.

20.3.2 Selected Results from the UCL EPICENTRE Questionnaire

20.3.2.1 Risk Perceived as Most Threatening in Each Culture and Group

The first step in the questionnaire protocol was to present participants with a list of 21 different societal risks spanning both natural and human-made hazards. Participants were asked to choose which five of these risks were most threatening to them personally, and order them from the most threatening to the fifth most threatening. Responses were reverse-coded so that the fifth most threatening hazard was scored one, the fourth most threatening scored a two, and so on. Response means were then calculated for the country samples to obtain within-sample average threat perceptions. In this way we aimed to examine overall risk concerns across and within our study locations. Figure 20.1shows the risk rankings across all hazards for all three countries.

Looking at the top five hazards per country, we see that earthquakes are included in all three countries as one of the most significant hazards, and are the only natural hazards to be so (see Table 20.2). However, there are differences in how threatening earthquakes are perceived to be. The Japanese respondents are clearly more concerned about earthquakes than the US or Turkish respondents. Two other questions measured facets of seismic risk perception relating to expectations of safety. The first of these read: *How safe would you feel inside your house if a large earthquake occurred?* , with responses measured on a Likert scale ranging from 4 (completely safe) to 1 (not safe). The second of these read: *I am confident that it will probably not be seriously damaged in a major earthquake* , with "it" referring to the respondent's house.

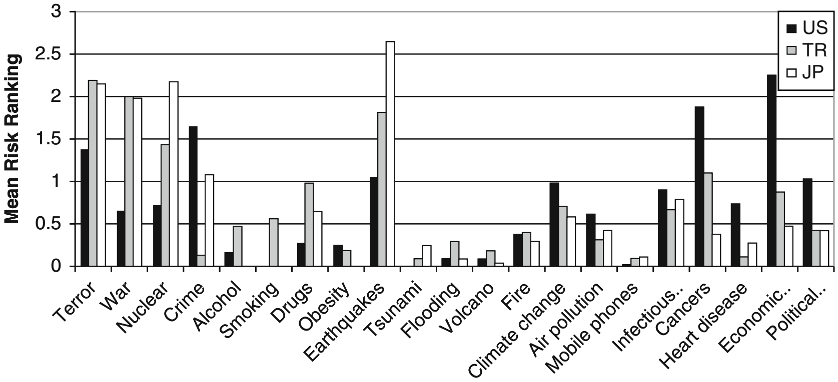

Fig. 20.1 Mean risk rankings by country and hazard

Table 20.2 The five most threatening hazards per country

Rank	USA	Turkey	Japan
1	Economy (2.25*)	Terror (2.18)	Earthquakes (2.64)
2	Cancer (1.87)	War (2.0)	Nuclear (2.17)
3	Crime (1.64)	Earthquakes (1.81)	Terror (2.14)
4	Terror (1.37)	Nuclear (1.43)	War (1.98)
5	Earthquakes (1.04)	Cancer (1.1)	Crime (1.08)

*Numbers in parentheses represent mean risk score, range 0 to 5

Agreement with this answer was indicated by ticking a box, disagreement was indicated by leaving it un-ticked. Accordingly, answers to the first question were summarised as averages across respondents, while the second was computed as the percentage of yes responses. Table 20.3 below summarises the scores across the three samples.

The Japanese respondents, who felt most threatened by earthquakes as measured by the initial risk ranking (Table 20.2), are the most confident that their houses will not sustain serious damage in a major earthquake. The opposite pattern is seen among US respondents. While they expect to feel fairly safe inside their houses in a major earthquake, they are the least confident that the house itself will not be seriously damaged. Finally, the Turkish respondents occupy a middle ground between the US and Japanese responses. While their expectations of safety are fairly positive, they are much less confident than the Japanese, and only slightly more so than the US respondents.

Table 20.3 Responses to risk perception questionnaire items

	USA	Turkey	Japan
How safe would you feel...	2.61	2.15	2.12
I am confident...	27%	33%	46%

In the US and Turkish samples, perceived safety of oneself and confidence in structural integrity were significantly and positively correlated (USA: $r = .4, p < .001$, 2-tailed; Turkey: $r = .715, p < .001$, 2-tailed), while seismic risk ranking was not significantly correlated with either of the other two measures. In the Japanese sample none of the three variables was significantly correlated.

We also analysed our three risk perception measures to see whether there were differences in responses across demographic characteristics such as age, gender, income level, residence type (house, apartment or other), marital status and education. Among our Turkish respondents there were significant differences only within two demographic strata, both relating to expectations of safety. Respondents aged 50 or more were less likely to believe they would be safe inside their houses in the event of a major earthquake ($M(\geq 50) = 1.63$, $M(<50) = 2.0$, $t(39) = 2.47$, $p = .016$). Those who were married or cohabiting with a partner ($N = 26$) were more likely than single respondents ($N = 22$) to feel safe inside their houses in the event of a major earthquake, with $M = 2.15$ for the first group and $M = 1.41$ for the second group ($t(39) = 2.4, p = .021$).

Among our Japanese respondents there were three significant demographic differences. Men expressed more confidence that their houses could withstand a major earthquake relative to women (61% versus 29% yes responses, $t(45) = 2.25$, $p = .029$). Those living without children ($N = 22$) were more confident in their home's structural integrity than respondents from households with children, (64% versus 31% yes responses, $t(46) = -2.35$, $p = .023$). Finally, Japanese respondents aged 50 years or over were more likely to believe they would be safe inside their houses in the event of a major earthquake than those below 50 ($M(\geq 50) = 2.38$, $M(<50) = 1.86$, $t(40) = 2.21$, p.033), which is exactly opposite to the pattern found in the Turkish data.

In the US sample we found differences between three demographic strata, all on the item measuring confidence in their home's structural integrity. Respondents living without children in the household ($N = 32$, 2 missing) had higher confidence in their home's structural integrity than those with children in the household ($N = 14$, 35% versus 7% yes responses, $t(46) = -2.56$, p. =.014). Those aged 50 and over were also more confident than those below 50 (40% versus 13% yes responses, $t(46) = 2.19$, $p = .034$). Similarly, single respondents ($N = 18$) were more confident than married or cohabiting respondents ($N = 30$, 44% versus 17% yes responses, $t(46) = -2.15$, $p = .037$).

The characteristics of groups with lower risk perceptions in the three countries are summarised in Table 20.4. Clearly there are differences in the three country samples. Some similar characteristics are seen among the US and Japanese respondents, which resemble those identified in previous studies concerning low risk perception (see Table 20.1). These results confirm the importance of considering cultural differences in assessing risk perception.

20.3.2.2 Seismic Adjustments

Using a scale adapted from Spittal et al. (2006) we asked respondents to indicate which of a range of 19 mitigative and preparatory seismic adjustments they had

Table 20.4 Characteristics of groups with lower risk perceptions per country

Country	Characteristics of groups with low risk perception
USA	People aged above 50 years
	Households without children
	Single people or people living alone
Turkey	People aged below 50 years
	Married or co-habiting people
Japan	People aged above 50 years
	Households without children
	Men

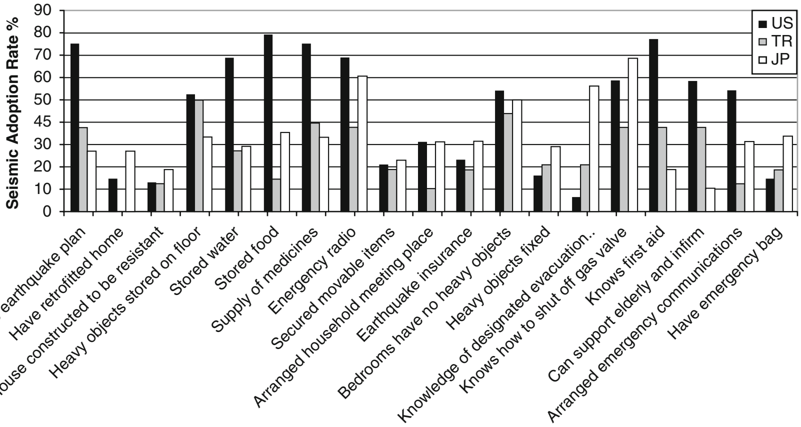

Fig. 20.2 Seismic adjustment by type and country

adopted. Figure 20.2 shows the distribution of adjustment adoptions across the three samples.

There are clear differences in terms of the average number of adjustments adopted, as well as what types of adjustments are adopted. The mean number of seismic adjustments adopted in the US sample is 9.19, in the Turkish sample 5.25, and in the Japanese sample 6.83. These differences are statistically significant ($F_{(2.141)} = 13.816$, $p < 0.0005$).

It is important to know what types of adjustments are favoured among our respondents. We divided seismic adjustments into two types: those that seek to mitigate and reduce damage from earthquakes through retrofitting, aseismic construction and securing of potentially dangerous home contents; and those preparatory adjustments that increase survival chances after the event, such as stockpiling essential food and medicines, having earthquake insurance, family disaster plans, etc. The first category contains six items, whereas the second category contains 13 items. Table 20.5 lists the mean number of adjustments adopted in each category by each country, and what percentage of the maximum number of adjustments the

Table 20.5 Mean adjustment adoption rates by type, country and proportion of maximum

	Mitigative Adjustments		Preparatory Adjustments	
Country	Mean number	Mean as% of max	Mean number	Mean as% of max
USA	1.71	28.5	7.23	55.61
Turkey	1.46	24.33	3.5	26.92
Japan	1.71	28.5	4.67	35.92

mean constitutes. It is clear that preparatory adjustments are more popular, whilst mitigative adjustments have an extremely low uptake. This is consistent with findings from others, e.g. Kirschenbaum (2005). In particular, structural retrofitting is seen to be unpopular, with no occurrence of this adjustment measure seen in our Turkish respondents and low occurrences in the other countries.

As previous research has indicated that seismic adjustment rates differ along demographic divides such as age, gender, education, income and marital status, we applied t-tests on the country samples for both types of adjustments. In the US sample the only significant difference as regards mitigative adjustments was between those aged 50 or over, and those below (this threshold was chosen as it bisected the sample in two equal halves; this also applies to the samples from Turkey and Japan). Those aged 50 or over were more likely to have adopted mitigative adjustments than those below ($M=2.12$ adjustments for ≥ 50 years, $M=1.26$ for <50 years, $t(46)=2.13$, $p=.038$). Analysing preparatory adjustments there were two group differences. Again those aged 50 or over were more likely to have adopted preparatory adjustments ($M=8.24 \geq 50$ years, $M=6.13<50$ years, $t(46)=2.51$, $p=.016$). Compared to participants living in apartments ($N=11$, $M=5.36$), those living in houses were more likely to have adopted preparatory measures ($N=37$, $M=7.78$, $t(46)=2.41$, $p=.02$).

In the Turkish sample we only found one significant group difference, between those married or living with partners versus single participants when analysing mean scores for preparatory adjustments. Those married or living with partners had a mean rate of 4.45, while singles had a mean rate of 2.69 ($t(46)=2.15$, $p=.037$).

Finally, in the Japanese sample we likewise found only one significant difference on group mean scores. As regards preparatory seismic adjustments, those living in households earning less than the median household income had a greater adoption rate ($M=5.42$) than those from households with above-median household incomes ($M=3.92$, $t(46)=2.14$, $p=.037$).

Table 20.6 summarises the characteristics of the respondents in each country who are less likely to have carried out seismic adjustments, and who might therefore be deemed to be at higher physical risk from an earthquake. Given that there are some differences between groups with low risk perception (Table 20.4) and low rates of seismic adjustment, the question raised is whether there is a correlation between risk perception and seismic adjustment.

Table 20.6 Characteristics of groups less likely to have carried out seismic adjustments

	Vulnerable Group Characteristics	
Country	Mitigative Adjustments	Preparatory Adjustments
USA	People aged below 50 years	People aged below 50 years People living in apartments
Turkey		Single people
Japan		Households with above median incomes

Table 20.7 Correlations between risk perception and seismic adjustment measures

	Correlations	
	Mitigative Adjustments	Preparatory Adjustments
Perceived safety of house	0.119	0.172
House will not sustain major damage	0.069	0.144
Earthquake risk ranking	-0.151	-0.006

20.3.2.3 Does Seismic Risk Perception Correlate with the Adoption of Seismic Adjustments?

Table 20.7 presents the correlations between risk perception measures and the number of adopted mitigative and preparatory adjustments for all three countries considered jointly. It is found that there are no significant correlations between these factors. This is also true within individual country samples.

These initial quantitative findings therefore do not support the assumption that seismic risk perception is correlated to seismic adjustment. This observation is in general agreement with past studies that find a weak or non-significant link between these factors (e.g. Lindell and Prater 2000; Perry and Lindell 2008). These observations strengthen the authors' argument that psychological factors other than risk perception should be understood to better explain seismic adjustment rates.

20.4 Conclusion

This paper provides an overview of the psychology literature on seismic risk perception with a view to highlight the psychological drivers of seismic adjustment behaviours on the part of individuals. The review shows that there are a number of factors that contribute to the adoption of seismic adjustment measures, which include people's perception of seismic risk, sense of belonging in a community, sense of trust, sense of responsibility and sense of control. It is argued that a better understanding of these fundamental motivations within a given socioeconomic and cultural setting, and explicit inclusion of these in the design of disaster risk reduction and communication activities, may lead to more effective promotion and potentially higher rates of adoption of seismic adjustment measures.

The authors describe a new study being carried out to better understand the psychological drivers of seismic adjustment of individuals and households. The study is composed of two parts: in-depth interviews with respondents in Turkey, Japan and the US, and a supporting questionnaire. This paper presents some of the initial findings from the questionnaires that examined the respondents' perception of earthquake risk and seismic adjustment rates. Lack of correlation between these casts doubts on the assumption of a direct link between risk perception and adoption of seismic adjustment behaviour. Risk perception is not simply a matter of rational calculation of outcome probabilities and the authors state that emotive, symbolic and other subconscious factors may play a role, as might societal factors. Thus the main body of the UCL study, a qualitative study of the emotive and symbolic pathways of thought in three cultures, is likely to illuminate the issue of what drives human vulnerability to earthquakes.

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