
GeoHazards International

United Nations Centre for Regional Development


# GESI

## Global Earthquake Safety Initiative

**Pilot Project**

bandung, indonesia     islamabad, pakistan     tijuana, mexico

# Global Earthquake Safety Initiative Pilot Project

## Final Report

GeoHazards International

United Nations Centre for Regional Development
Disaster Management Planning Hyogo Office

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# PREFACE

AS the Global Earthquake Safety Initiative (GESI) Pilot Project was drawing to a close, the world witnessed two earthquake disasters, striking countries on opposite sides of the earth: India and El Salvador. It is reported that tens of thousands of lives and billions of dollars were lost. For El Salvador, emerging from decades of civil war and with half its population below the poverty line, the losses were devastating—0.02% of its population and 10% of its GDP. For the U.S., with its larger economy and population, this is equivalent to losses of 55,000 lives and $900 billion; for Japan, it is equivalent to losses of 25,000 lives and $400 billion. And the toll cannot be measured in lives and dollars alone. The entire world shuddered at images of Indian children crushed while sitting at their school desks or while marching in a holiday parade.

Learning of such disasters is especially distressing for people like the members of the GESI Team, who are familiar with earthquake risk. As it is for everyone, it is painful for us to see the suffering of already impoverished people and innocent children. It is even worse because for us these disasters are no surprise. Studies of earthquake disasters always reach the same conclusions: communities should enact and enforce modern building and land-use codes, strengthen and prepare medical care facilities, and train and equip emergency response agencies. The response to earthquake disasters is also depressing because, for a fraction of the reconstruction costs, the losses could have been reduced or even avoided through mitigation and preparedness beforehand. Finally, these disasters are disturbing because they divert the world's attention from the hundreds of communities that are as or more vulnerable than those just struck.

Thus, while we mourn the Indian and Salvadoran victims and sympathize with the survivors, our energies are directed to avoiding such disasters elsewhere in the future. We wish to alert threatened cities of their danger and help them reduce their future death and suffering. This is our mission and the focus of the GESI Pilot Project.

This report summarizes the GESI Pilot Project. Chapter 1 describes the problem this project addresses. It documents the increase of earthquake risk in developing countries over the past century, and proposes that the persistence of this risk is due to low awareness of the risk and of affordable means to manage it. Chapter 2 describes a method that GHI developed over the last two years to assess community earthquake safety. This method is designed to raise awareness of the world's rapidly increasing urban earthquake risk and to identify the most effective ways to manage it. It measures the risk of life loss due to earthquakes, identifies its sources, evaluates the various means to manage it, and allows a comparison of the risk of communities with similar economies, governments, or cultures. Chapter 3 summarizes the joint work of GeoHazards International (GHI) and the UN Centre for Regional Development (UNCRD) to apply this method to twenty-one cities around the world, and to evaluate this method—to determine if it is useful, defensible and understandable, and if its application has the potential to improve earthquake risk management worldwide. This chapter lists the cities that participated. It discusses the data collection process and the results obtained. Finally, it describes how the results were evaluated. Chapter 4 presents our conclusions. This report also includes five appendices, which provide a summary of the project advisory committee meetings, the technical description of the methodology, sample questionnaires, the risk summary for Antofagasta, Chile, and a summary of the evaluation workshops.

# ACKNOWLEDGEMENTS

WHILE GHI conceived of the GESI Pilot Project, and GHI and UNCRD personnel comprised the majority of the GESI Team, this is the work of many people and many organizations from around the world.

In addition to GHI and UNCRD, various organizations provided funding. The OYO Corporation of Japan generously supported the development of the method and the Pilot Project. Without OYO's support, this project would have been impossible. The US Office of Foreign Disaster Assistance (OFDA) provided substantial fiscal support, and senior OFDA staff participated in the Kobe Evaluation Workshop. The Sanwa Bank of California supported an intern who worked on GESI. The UN International Decade for Natural Disaster Reduction and the Asian Disaster Reduction Center supplied additional funds. Funding from the Great Hanshin-Awaji Earthquake Memorial Research Institute helped make possible the publication of this report, and, with additional support from the Yomiuri Shimbun, the Kobe Evaluation Workshop. The Municipality of Quito and the UNCRD Project Office for Latin America and the Caribbean provided essential logistical and financial support for the Quito Evaluation Workshop.

As important to the success of this project as funding were the time, advice and encouragement contributed by the hundreds of people in the twenty-one cities who participated in GESI. These people generously volunteered to collect data, provide advice, and evaluate the method. They did so in the hopes that this method would help not only their own communities but also other earthquake-threatened cities around the world. The participants of the two evaluation workshops provided particularly helpful advice.

Yuko Nakagawa and Yuriko Tsunehiro, of the UNCRD Disaster Management Planning Hyogo Office, were essential in organizing and conducting the Kobe Evaluation Workshop. Vannina Grijalva of the Office of International Affairs of the Municipality of Quito, Jeannette Fernandez of Ecuador's Escuela Politecnica Nacional, and Claudia Hoshino and María Helena Rodriquez of the UNCRD Latin America and Caribbean Office helped organize the Quito Evaluation Workshop.

Particular gratitude is owed the members of the Project Advisory Committee, who generously gave their time. They met for four all-day meetings as a full committee and several additional times as sub-committees to offer critical advice, and they were available for consultation between meetings. They helped us balance a multitude of competing demands. Their faith in the value of this work sustained us. Bill Iwan adroitly chaired this committee. In addition, he helped design the Evaluation Workshops, and acted with great skill and sensitivity as moderator of the Kobe Evaluation Workshop.

Carlos Ventura of the University of British Columbia volunteered to gather data, critique results, lead the post-earthquake investigation to El Salvador, participate in the Kobe Evaluation Workshop, and serve as moderator of the Quito Evaluation Workshop.

Rachel Davidson assisted throughout this project, as a volunteer. In addition to giving us a starting point, with her Earthquake Disaster Risk Index, she helped design the questionnaires, enthusiastically participated in the Project Advisory Committee meetings, and led a working group in the Kobe Evaluation Workshop.

# Chapter 1

# INTRODUCTION

URBAN earthquake risk is greatest and most rapidly growing in developing countries. In 1950, slightly more than half the urban population at risk from earthquakes lived in developing countries; in the year 2000, that number increased to more than 85% (Figure 1).

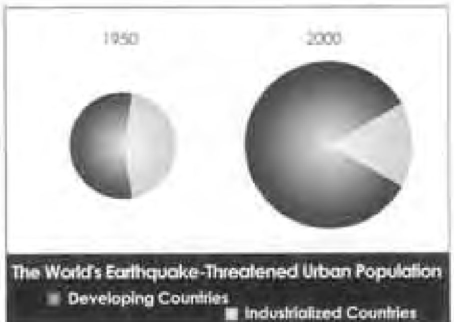



Fig. 1 The world's urban population is becoming more earthquake threatened, particularly in developing countries.

While developing nations bear a disproportionate burden of earthquake risk, very little of the world's spending on earthquake engineering research is aimed at their needs. Tucker *et al.* (1994) estimate that over the last 50 years the portion of the world's annual earthquake engineering research focused on the needs of developing countries has remained fixed at about 15% (Figure 2).

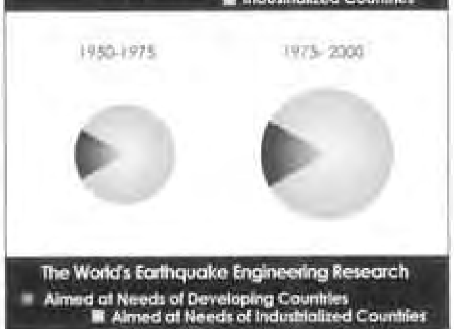



Fig. 2 The portion of the world's expenditures on earthquake engineering research that is aimed at the needs of developing countries remains small.

The consequences of this disparity are not surprising. Over the last century, the average lethality of earthquakes in the United States and Japan plunged while the lethality of earthquakes in developing countries remained high (Figure 3). According to the Office of U.S. Foreign Disaster Assistance (Labat-Anderson, 1991), both developing and industrialized nations suffered approximately twelve thousand deaths per lethal earthquake in the first half of the 20th century. In the latter half, the number of deaths per earthquake in industrialized nations dropped


Fig. 3 During the last century, the lethality of earthquakes in industrialized countries has decreased by a factor of ten (presumably as a result of better construction design and practice, urban planning and emergency response), while the lethality of earthquakes in developing countries has remained high.

by an order of magnitude, with no corresponding decrease for developing nations.

It is clear that unless something is done quickly to significantly improve the urban earthquake risk of developing countries, earthquakes will cause increasingly greater human and economic losses in these countries, further delaying their development.

But the problem is not so much the *existence* of great and rapidly increasing urban earthquake risk in developing countries as the *persistence* of this risk. The risk has been great and increasing over the last century and, compared with the risk in industrialized countries, not much has been done about it. It is not even widely acknowledged.

This persistence cannot be explained or justified on the grounds that people in developing countries face a multitude of apparently more serious problems—war, hunger, unsafe water, AIDS, to name a few. Because these problems claim new victims every day and because their future victims are easily identified, they are salient in the minds of decision makers. This does not mean, however, that they are more important or more cost effective to solve. If the public and public officials of threatened countries knew of their earthquake risk, particularly for their children; knew of affordable means to reduce it; and knew that their risk was significantly greater than the risk from other problems, or than the earthquake risk of comparable communities, then they might urge that more be done to improve their communities' earthquake risk management. Unfortunately, public policy has not been based, even very loosely, on comparisons of either the magnitudes of problems or the improvements possible per dollar invested. With so little awareness of the problem and its solution, informed decisions are not possible.

Based on observations over the last decade, it is believed that the disproportionately great urban earthquake risk in developing countries persists primarily because of a low awareness—in these countries and internationally—of that risk and of affordable means to manage it.

This report summarizes one effort to correct this situation. The Global Earthquake Safety Initiative Pilot Project undertaken by GHI and UNCRD tested a method of assessing community earthquake safety.

The objective of this method is to:

(1) express urban earthquake risk in lay terms,

(2) measure trends in the urban earthquake risk of the world's major cities,

(3) evaluate the effectiveness of various means of reducing earthquake casualties, and

(4) highlight the increasing earthquake risk of schools of developing countries and the potential for reducing that risk.

This method focuses on the risk of only life loss in earthquakes. Earthquakes cause many other important losses - including economic, political and cultural - which are not considered. The possible users of this method are primarily city, national, and international decision makers. The next chapter describes this method.

Chapter 2

# METHOD

THE GeoHazards International (GHI) method of assessing community earthquake safety estimates the risk of life loss from earthquakes in cities around the world. The algorithm is inspired by loss estimation and produces results that indicate the relative severity of cities' earthquake risk, the sources of risk within each city, and the relative effectiveness of potential mitigation options. The same results are also produced for the risk of school children.

## History

The GHI method is the result of the work of numerous people over many years. This section describes the development of the method, which is summarized in Figure 4.

### Earthquake Disaster Risk Index

In a doctoral dissertation at Stanford University, Rachel Davidson developed and tested an Earthquake Disaster Risk Index (EDRI) (Davidson, 1997). The EDRI is a composite index that directly compares the overall earthquake disaster risk of cities worldwide and describes the relative contributions of various factors to that risk. The EDRI adds the following five indicators together to rate each city's risk: Hazard, Exposure, Vulnerability, External Context, and Emergency Response and Recovery. The EDRI was designed to use data collected in a library, and was demonstrated by evaluating ten cities around the world.

### Understanding Urban Seismic Risk Around the World

The EDRI was applied to twenty cities around the world in the *Understanding Urban Seismic Risk Around the World* (UUSRAW) Project, which GHI implemented as part of the *Risk Assessment Tools for Diagnosis of Urban Seismic Disasters* (RADIUS) initiative of the United Nation's International Decade for Natural Disaster Reduction. Instead of using library research, data were collected by sending questionnaires to local earthquake professionals in participating cities.

In October 1999, the representatives of the twenty cities that participated in UUSRAW gathered

Fig. 4 A summary of the development and implementation of the EDRI and the GHI method. Both estimate the earthquake risk of a city. They differ in their definition of earthquake risk and in the way the data are collected and combined.

| Project | Earthquake Disaster Risk Index (EDRI) | UN- Understanding Urban Seismic Risk Around the World (UUSRAW) | GHI Method | Global Earthquake Safety Initiative (GESI) |
|---|---|---|---|---|
| Method | Earthquake Disaster Risk Index (EDRI) | | GHI Method | |
| Objectives | Research and Development | Test | Research and Development | Test |
| Time Frame | 1994- 1997 | 1998- 1999 | 1999- 2000 | 2000- 2001 |
| Definition of Risk | Earthquake 'Disaster' | | Earthquake Lethality | |
| Basis of Method | Composite Index | | Loss Estimation | |
| Mode of Data Collection | Library | Email Questionnaire | Library | Interviews in Cities |
| Number of Cities Participating | 10 Cities | 20 Cities | 10 Cities | 21 Cities |

**Development and Implementation of the EDRI and GHI Method**

at an international symposium to evaluate RADIUS (Cardona *et al.*, 2000). They concluded that while there was potential for a similar project to improve risk management, the EDRI's method, based on the linear combination of indicators was disturbing because it was not based on physical principles. This conclusion motivated GHI to develop a new method, incorporating the lessons learned from the UUSRAW project.

### Project Advisory Committee

GHI created a Project Advisory Committee to assist in the development of this new method. This committee brought together eight people whose backgrounds included seismology, earthquake engineering, urban planning, and disaster management. Together, these people helped identify the goals of the GHI method and assess the three algorithms that were investigated during the two years of research, development, and testing. Summaries of the Project Advisory Committee meetings outlining the development of the GHI method can be found in Appendix 1.

## Overview

This section describes components of the GHI method: the algorithm, data collection, and results.

### Algorithm

Figure 5 illustrates how cities' earthquake lethality potential is calculated.

On the lower right hand side of Figure 5 is Earthquake Lethality Potential, the value calculated by the GHI method. Earthquake Lethality Potential can be regarded as an estimate of the number of lives that would be lost if all parts of the city, as it exists today, experienced shaking at the level that has a 10% chance of being equaled or exceeded in 50 years. This value is not equivalent to the results produced by a scenario analysis, which would represent the likely casualties from a single shaking event and would take such factors as time of day and season of year into account. Instead it is a composite measure, adding estimates of the risks faced by all parts of the city from all possible earthquakes.

The gray column in Figure 5 contains the fatality and life-saving potentials (outlined in white) that contribute to the total Earthquake Lethality Potential: deaths caused by building collapse, earthquake-induced landslides, and post-earthquake fires and lives saved by organized search and rescue and medical care. Life-threatening injuries and fatalities caused by building collapse and earthquake-induced landslides are added together and reduced by organized search and rescue. Injuries and fatalities caused by post-earthquake fires are added to this total. Finally the total injured is reduced by the effects of medical care; injured people who do not receive medical attention become fatalities and are added to the total Earthquake Lethality Potential. Once Earthquake Fatality Potential is totaled, the fatalities caused by emergency response problems are calculated independently. Introducing emergency response as an independent cause of fatalities means that the risk must be redistributed among the other fatality and life saving potentials, which are recalculated and reported as percentages of the total city risk, as seen in the blue-gray column at the far right in Figure 5.

The horizontal bands in Figure 5 indicate how the components of risk are calculated. The basic structure of each calculation is the same: the most important indicators are shown in yellow on the left, and are combined to determine the potential for various types of damage, shown by the blue squares. The corresponding risk of death and injuries is then estimated, as represented by the green squares. The injuries and fatalities are combined to produce the fatality and life saving potentials in the gray column.

The indicators used to calculate each component are discussed below. The term 'indicators' means the data needed by the algorithm to complete the calculation. In many cases, because the necessary information was unavailable, a proxy was used to represent the needed information.

1) **Building Fatality Potential.** Indicators measure the ground shaking on firm and soft soils; the building stock; the quality of building design, construction and materials; the weight of the buildings; and the building occupancy rates.

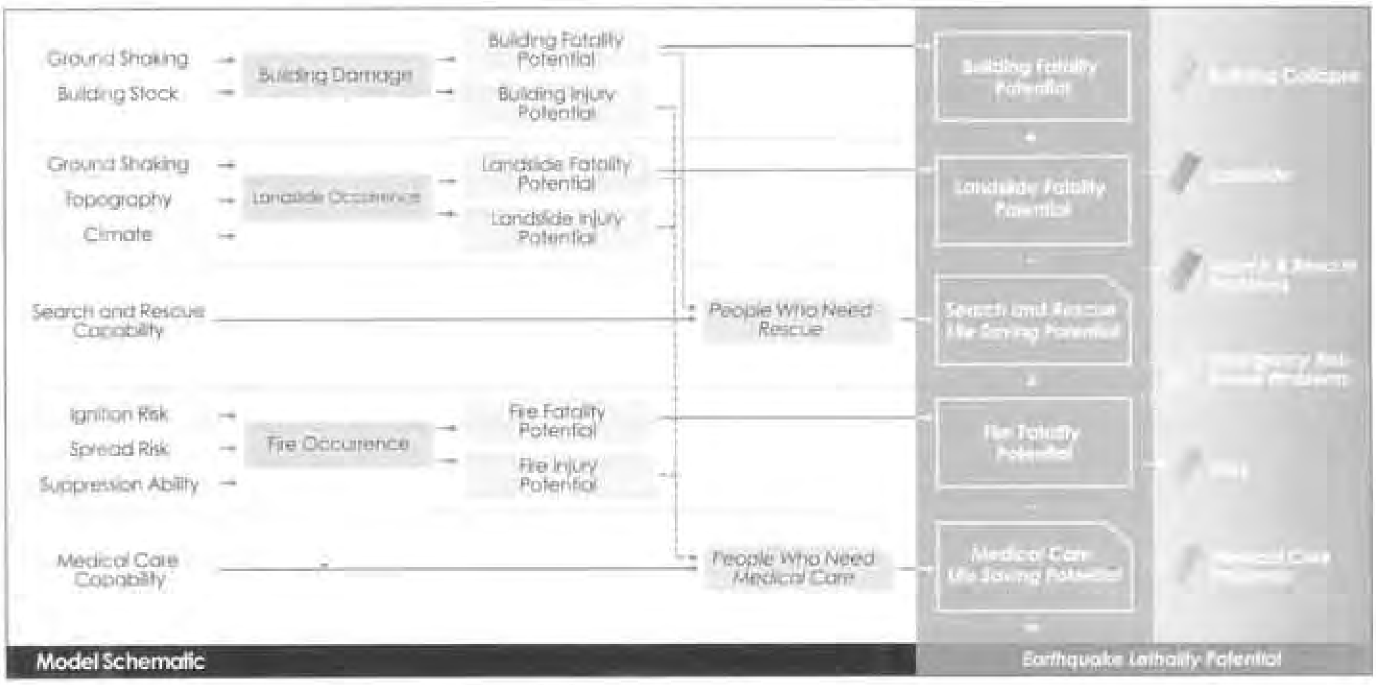
2) **Landslide Fatality Potential.** Indicators measure the ground shaking; the percentage of the city area likely to slide; the average annual rainfall; and the population density of the area that is affected by slides.

3) **Search and Rescue Life Saving Potential.** The indicator measures the number of people available to participate in organized search and rescue and their training and effectiveness.

4) **Fire Fatality Potential.** Indicators measure the ground shaking; the amount of infrastructure damage; the annual average wind speed; the prevalence of flammable buildings and materials; the density of structures; the sources of available water; the ease of access for fire trucks and other equipment; the capacity of the fire department; and the capacity of the city to respond to emergencies.

5) **Medical Care Life Saving Potential.** The indicator measures the capacity of the medical community to handle many casualties after a damaging earthquake (this takes into account the possibility that the medical capacity might be reduced).

Fig. 5 A summary of the GHI method for the estimation of a city's Earthquake Lethality Potential, which is a combination of five factors: building fatality potential, landslide fatality potential, search and rescue life saving potential, fire fatality potential and medical care life saving potential. Once Earthquake Lethality Potential is totaled, emergency response is calculated as an independent cause of fatalities, which causes a redistribution.



The details of the Method are given in Appendix 2.

### Data Collection

The GHI method collects data through interviews and workshops conducted in the cities, in which specialists from a wide range of fields and institutions describe aspects of their city that contribute to risk and discuss risk management activities already in effect. A City Team Leader acts as the primary contact and is responsible for identifying the experts who supply the data.

This approach improves the data quality over the approach of collecting data remotely. The EDRI relied exclusively on library data and was efficient in terms of time and money, but the data were limited to what was published officially, and no one in the cities participated. The UUSRAW project emailed a questionnaire to city representatives. While this method included city participation, soliciting responses was difficult. The GHI method's investment not only improves data quality, but also raises local awareness of the problem and the available solutions, and encourages local commitment to the results.

Eight questionnaires were developed to collect the needed information; each targets a particular field or specialty:

- Seismology, Soils, and Landslides
- City Planning
- Building Inventory
- School Buildings
- Emergency Response
- Medical Emergency Preparedness
- Hospital Emergency Preparedness
- Fire Preparedness

The complete City Planning and Emergency Response Questionnaires are presented in Appendix 3.

Data are collected for the greater metropolitan area, which is defined as the area with a common political representation that is closely linked by economic and social ties. Because this region coincides with the responsibility of local officials, it represents the natural constituency for risk management efforts. Information is collected for both the entire city and the public school system.

In all cases, attempts are made to use the best data available without conducting original research in the cities. Data are collected from published sources as well as from specialists in each city and from both official and unofficial sources in an attempt to represent the risk of the city as accurately as possible.

### Results

The GHI method was developed to reflect cities' earthquake risk in meaningful, easy-to-understand and motivational ways. Thus the results must be presented in ways that show city representatives that they can reduce their risk and that allow them to track changes in it. This in turn means that a city must have a reasonable idea of the present state of its risk, and must understand its components.

The GHI method produces results that: compare communities' risk of life loss caused by earthquakes, identify the sources of each city's risk, and evaluate the various means of reducing that risk.

The same results are presented for the school system.

Thus the results present two kinds of information about earthquake risk. One compares cities' risk, while the other describes the risk particular to each city. Information about their own risk helps city leaders set priorities, while information about other cities provides benchmarks for understanding how severe their risk is and for deciding what level might be acceptable.

## Validation

Several ways of validating the model have been contemplated. It would be ideal if there were enough data about historical earthquakes and the conditions in the cities they struck to fit the model and its parameters to known data. Unfortunately, such data do not exist. There is great uncertainty about the number of deaths caused even by many recent earthquakes, and trying to estimate the building stock and other relevant conditions of affected cities is more uncertain. Information about earthquakes in the past is more uncertain still. Nonetheless, continuing research into past earthquakes may still suggest values for specific model parameters and better ways of validating the model as a whole. In addition, it should be possible to ask international earthquake experts to rank cities according to their risks of life loss in earthquakes and see how well the GHI method matches the consensus of their views. Finally, over time, it should be possible to validate the method by comparing its results with the consequences of observed events. Chapter 3 discusses such a comparison carried out after the El Salvador earthquakes of January and February 2001.

## Discussion

### Life Loss

The GHI method measures risk in terms of only life loss. While earthquakes cause many other kinds of damage, none lends itself as well to simple, defensible measurement as life loss does. Earthquake damage includes the associated social and political disruption, but it is difficult to quantify such instability. Earthquakes also threaten cities' cultural heritages, but, again, this is difficult to evaluate. Somewhat easier to measure and predict are the immediate economic losses caused by earthquakes, but any economic measure should include the long-term repercussions to the city, region and world, which are much harder to assess. Attempts to measure earthquake risk exhaustively would combine the effects mentioned above, as EDRI does. However, the GHI method limits itself to life loss, because it seems to be the most motivational threat from earthquakes while also being easiest to model.

It has been argued that life loss alone will not motivate politicians; and that they will be more likely to act if they know probable economic losses as well. Until a method can be developed that measures the long-term economic repercussions of earthquakes, it may be adequate to state that cities with proportionally greater human losses are likely to suffer proportionally greater economic losses as well.

### School Systems

The GHI method places a special emphasis on public schools because they are not only particularly vulnerable to earthquakes but also particularly popular as targets of mitigation once people become aware of the need. Often public schools are built cheaply and quickly on unsuitable land, and the children who attend them are poorly prepared for a disaster. Many schools do not even have a budget for maintenance. Nevertheless, when parents, politicians, and the general community realize how dangerous this situation can be, they begin to regard school safety as an important and achievable goal.

### Loss Estimation Model

The algorithm used to analyze the data is inspired by loss estimation. Its results have an understandable unit–life loss–and reflect clear relationships between sources of risk and types of mitigation. A more subjective way of combining the data was also considered, which could more easily have incorporated information that did not fit naturally into a loss estimation framework. However, because the results of such an index would have no direct physical meaning, they would be more difficult to understand and defend. In addition, there would be no easy way to tie mitigation efforts to reduction in risk.

### Model Parameters

Once the framework of loss estimation was adopted, it remained to decide which parts of a full loss estimation could be combined into broad indicators of earthquake risk, taking into account the availability of different types of data. Unfortunately, as concepts get amalgamated, making the algorithm simpler and simpler, the exact meaning of the quantity measured tends to get less clear. For this reason, our results emphasize comparisons among cities rather than cities' individual scores, even though those scores do have a concrete, if rather abstruse, interpretation. In particular, the scores should not be interpreted as the losses that could be expected in any single earthquake scenario–issues like time of day, season of year and possible infrastructure failures are averaged, if they are explicitly treated at all.

For example, rather than attempting to integrate the probable experiences of each section of a city over the distribution of possible shaking, the method uses the single value of the peak ground acceleration (PGA) that has a 10% probability of being exceeded in 50 years. This choice means that the life loss calculated is an estimate of the expected number of deaths that would result if each part of the city simultaneously experienced that level of shaking, though it might not even be possible for the different parts of the city to experience it all at once. This choice of PGA provides an indication of how bad big, rare earthquakes in a city are, but not how bad smaller, more frequent earthquakes are.

Similarly, the model mostly ignores the geographical distribution of building types, assuming that the building stock profile provides a useful indicator of risk, without further specifying whether weaker structures tend to be located on more or less hazardous ground than stronger structures.

In order to forecast the effects of various mitigation options, the method assumes that population growth will occur at a constant rate equivalent to today's growth rate and that new construction will be directly proportional to that rate and will continue in the same patterns as is happening today.

In addition to questions of what to measure and in what detail, there were questions of how to combine the components of risk. Some examples are:

- Ground shaking on soft soil is amplified by a constant factor across all cities. The percentage of soft soil in a city is measured, but the precise properties of that soil are not. Rather than trying to differentiate cities according to soil properties that are difficult to measure, the method uses the portion of the city on soft soil as a proxy for the significance of soil in the overall risk.
- The method accounts for building collapse as though the percentage of affected people who die, the ratio of the number of deaths to the number of injuries that occur, the length of time trapped victims survive, and the time required to save such victims are the same for all cities. The values the method assigns to these quantities help determine how much of a city's risk is due to its emergency response capacity.
- The ratio of people living in high-, medium- and low-rise buildings is assumed to be the same across all cities.

To the extent possible, quantities that were not measured for each city but were assigned common values across all cities were based on published research or expert opinion. Nonetheless, as the model is applied around the world and tested against actual earthquake experiences, it and its parameters will continue to evolve.

Chapter 3

# APPLICATION

THE Global Earthquake Safety Initiative (GESI) Pilot Project applied the GHI method to twenty-one cities worldwide to evaluate its potential to improve earthquake risk management. Of particular interest were:

- the defensibility, understandability and reasonableness of the method's results,
- the feasibility of applying the method to a large number of cities, taking into account cost, time, data quality, access of local authorities, and receptivity of results,
- the potential of the method to motivate earthquake risk mitigation action, and
- based on that potential, its future applications.

The GESI Pilot Project spanned eighteen months, from January 2000 to June 2001 and was conducted by the GESI Team, which was formed by staff from GeoHazards International, the Disaster Management Planning Office of UNCRD, and the University of British Columbia.

Figure 6 summarizes the project's process. It consisted of six major activities: city selection, data collection, results calculation, results dissemination and review, method validation, and project evaluation.

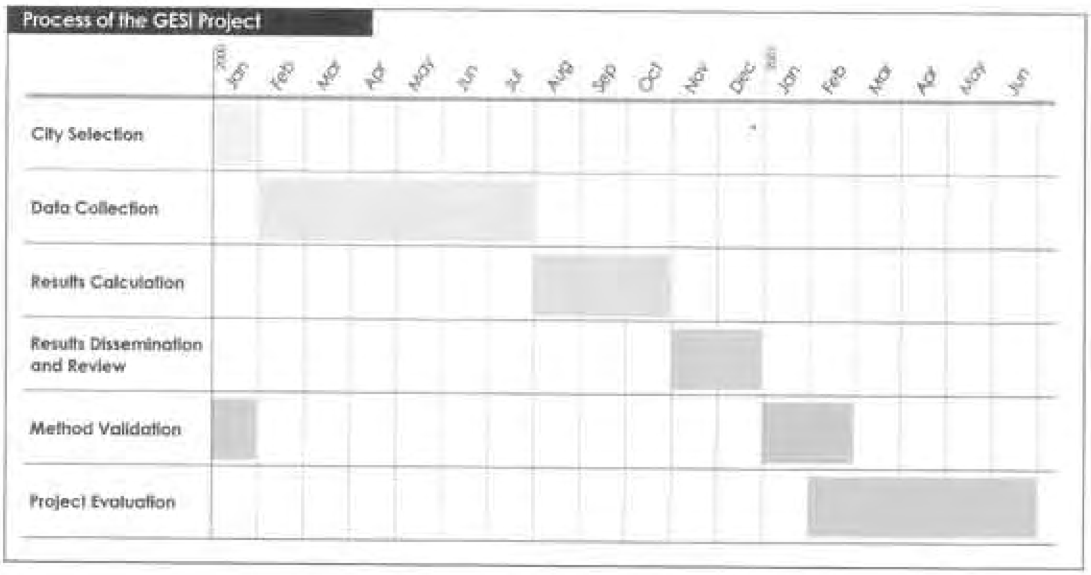
The next section describes these six activities in detail. The final section discusses a few significant issues encountered during the project.

## Process

### City Selection

The participating cities were chosen for the importance of their earthquake threat, the presence of local contacts of GHI and UNCRD, and the interest of these contacts in participating. The cities were located in the Americas and Asia. To ensure a representative sample of cities, the selected cities were small and large (populations from several hundred thousands to almost fifteen

Fig. 6 Process of the GESI-Pilot Project. The project was conducted over eighteen months and included twenty-one cities worldwide. The main activities were city selection, data collection, results calculation, results dissemination and review, method validation, and project evaluation. Local participants were actively involved throughout the project, especially in data collection and processing, review of results, and evaluation of GESI.




million), located in developing and industrialized countries (per capita GNPs from several hundred USD to several tens of thousands USD), and threatened by seismic hazard ranging from moderate to great (expected peak ground accelerations over 475 years from 0.15 g to 0.45 g).

After an initial screening, twenty-two cities were invited to participate in the project without compensation. All accepted and, except San Jose, Costa Rica, all participated in the project for its duration. The participating cities were:

**Antofagasta**, Chile
**Bandung**, Indonesia
**Delhi**, India
**Guayaquil**, Ecuador
**Islamabad/Rawalpindi**, Pakistan
**Istanbul**, Turkey
**Izmir**, Turkey
**Jakarta**, Indonesia
**Kathmandu**, Nepal
**Kobe**, Japan
**Manila**, Philippines
**Mexicali**, Mexico
**Mumbai**, India
**Nagoya**, Japan
**Quito**, Ecuador
**San Salvador**, El Salvador
**Santiago**, Chile
**Tashkent**, Uzbekistan
**Tijuana**, Mexico
**Tokyo**, Japan
**Vancouver**, Canada


**Fig. 7** The twenty-one cities that participated in the GESI Pilot Project. They include small cities (such as Antofagasta, Chile), and big cities (such as Delhi, India). They are located in industrialized countries (such as Japan) and developing countries (such as Nepal). In this figure, the size of the dots represents the population of the cities and the color their wealth in terms of their country's per capita GNP.

## Data Collection

The information required for the GHI method was collected through a series of interviews with local scientists, engineers, medical people, officials, and planners.

Although the same eight questionnaires were used to gather information in all of the cities, the process of data collection was different in each city. In most of the Asian cities, for example, members of the GESI Team carried out the interviews with local specialists and organizations. The City Team Leaders of each city arranged these interviews. In Tijuana and Antofagasta, on the other hand, the working groups that had been created for previous earthquake mitigation programs (Villacis and Cardona, 2000) led the data collection and carried out the interviews with local institutions. In Antofagasta, two journalists were hired for eight months to work full time preparing and conducting the interviews, processing the collected information, and coordinating the communication to the community of the findings and achievements of the GESI Pilot Project. In Mexico, the neighboring cities of Mexicali and Tijuana worked coordinately in the data collection and collaborated with each other throughout the project. In other cities, such as San Salvador, Guayaquil and Santiago, the collection of the city's earthquake risk information was incorporated into risk-management research projects by local universities. In Vancouver, one person collected all of the data.

In all cases, the City Team Leaders reconciled data from different sources, revised the collected information and identified data that needed verification. Additionally, public workshops were held in the Latin American cities to present and discuss the collected information and, in this way, improve its accuracy. In one city, for example, presentations at the workshop showed that information on hospitals' emergency

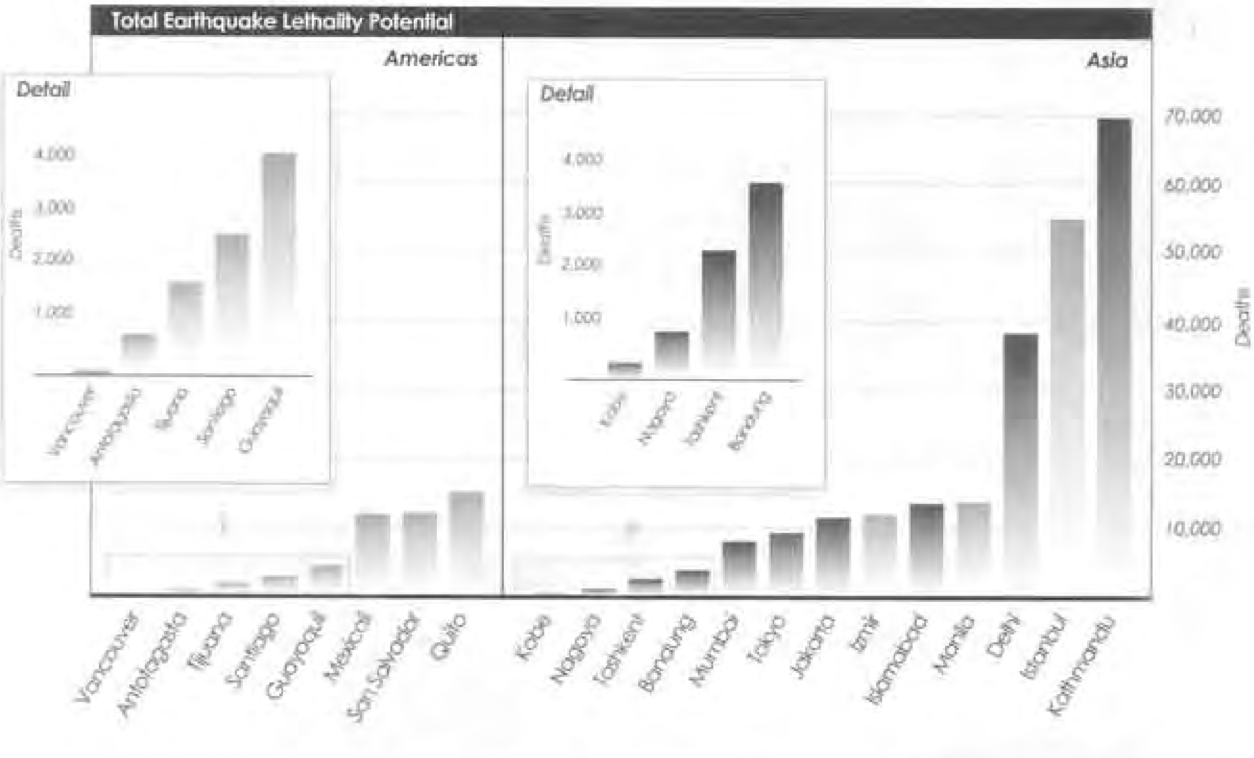



Fig. 8 The total earthquake lethality potential of the GESI pilot cities. Cities are classified by region (Americas, on the left, and Asia, on the right) and per capita GNP (red, over USD 10,000; green, between USD 1,000 and 10,000; and blue, under USD 1,000). For clarity, the results for the cities with lower earthquake lethality potential are shown in the detail graphs. The population of a city directly affects its total earthquake lethality potential, which is calculated as an estimate of the expected number of deaths that would result if each part of the city simultaneously experienced the ground shaking that has a 10% probability of being exceeded in 50 years. For this set of cities, Quito is most risky in the Americas and Kathmandu has the greatest risk in Asia.

preparedness provided by the hospital authorities was different from the information provided by the nurses working at those same hospitals, even though the same questionnaire was used to collect information from both groups. In another city, the emergency response organizations found that not only the information they were providing but also their daily activities were based on three different, not clearly related City Emergency Plans. The workshops helped the participants reach consensus about the information that best reflected the local reality. Since these workshops included representatives of the various sectors of society and of the mass media, they provided the additional benefit of raising awareness in the community about the city's earthquake risk. The participants could discuss, in many cases for the first time, the causes and characteristics of the city's risk, what had or had not been done to reduce that risk, and the coordination (or lack of it) among the city organizations in charge of managing that risk.

## Results Calculation

The GHI members of the GESI Team checked the collected information for completeness and compatibility. Working with the City Team Leaders through the Internet, the GESI Team completed missing information, put the data in a common format, and compiled it into a computer database.

The GESI Team applied the GHI method to calculate preliminary results for both the entire cities and their school systems. The calculated results included a comparison of total and per capita earthquake lethality potential among the participating cities, a breakdown of the sources of this earthquake lethality potential in each city, and an analysis of the effectiveness of risk mitigation options for each city. *All of these results are preliminary.*

### *Earthquake Lethality Potential*

Figure 8 compares cities according to the likely lethality of earthquakes. These numbers

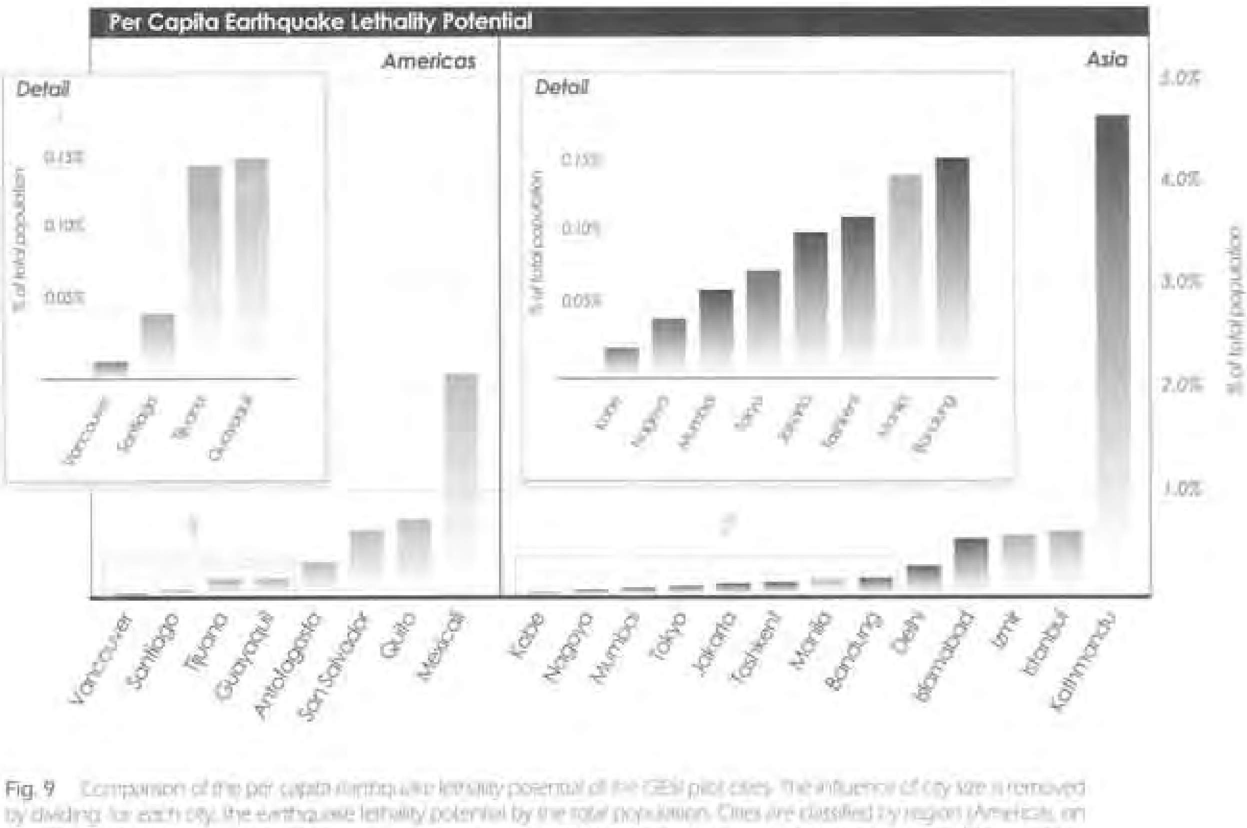



Fig. 9 Comparison of the per capita earthquake lethality potential of the GESI pilot cities. The influence of city size is removed by dividing, for each city, the earthquake lethality potential by the total population. Cities are classified by region (Americas, on the left, and Asia, on the right) and per capita GNP (red, over USD 10,000; green, between USD 1,000 and 10,000; and blue, under USD 1,000). For clarity, the results for the cities with lower per capita earthquake lethality potential are shown in the detail graphs. In the American region, according to these preliminary results, a person living in Mexicali, for example, is about three times more likely to be killed by an earthquake than a person living in Quito and about ten times more likely than a person living in Santiago. In the Asian region, a person living in Kathmandu is about nine times more likely to be killed by an earthquake than a person living in Islamabad and about 60 times more likely than a person living in Tokyo.

Fig. 10 Comparison of the sources of earthquake lethality potential in Delhi and San Salvador. According to these preliminary results, while most of the deaths in Delhi will be due to building collapse, an important fraction of the deaths in San Salvador will be due to earthquake-induced landslides. Also, while nobody is expected to be killed by earthquake-induced fires in San Salvador, many people may be in Delhi. Consequently, what Delhi needs to do to reduce its risk is quite different from what San Salvador needs to do.


Fig. 11 Effectiveness of four hypothetical mitigation actions in San Salvador and Delhi. While the most effective means, among the options considered here, of reducing risk in San Salvador is to site buildings safely (e.g. to avoid landslide prone areas) for the next ten years, constructing buildings well for ten years and improving medical preparedness are the most effective in Delhi.


represent composite losses, not the number of deaths expected for any specific earthquake. Although the value of each city's earthquake lethality potential in isolation has a complicated interpretation, the cities' relative scores indicate the different magnitudes of life loss they may experience, and therefore, they highlight where the risk is higher.

***Per Capita Earthquake Lethality Potential***

The results presented in Figure 9 attempt to personalize earthquake risk by comparing cities on the basis of the probability of an individual being killed by an earthquake. The influence of city size has been removed by dividing, for each city, the earthquake lethality potential by the total population. In this way, these results treat small cities and large cities alike.

***Sources of Earthquake Lethality Potential***

As an example of the use of the method to identify the sources of cities' earthquake lethality potential, Figure 10 shows the very different relative importance of the various sources of earthquake lethality potential in Delhi and San Salvador. According to these preliminary results, most of the deaths in Delhi will be due to building collapse, whereas an important fraction of the deaths in San Salvador will be due to earthquake-induced landslides.

Measuring the relative importance of the various sources of a city's risk is necessary to determine the best measures to reduce that risk. For example, according to the results presented in Figure 10, investing in Search and Rescue would not be significantly beneficial either in San Salvador or in Delhi, because neither city is likely to suffer significant life loss because of inefficient Search and Rescue operations. This does not mean that, especially for a populous city such as Delhi, many lives will not be saved by Search and Rescue. Rather, it means that compared to other sources of risk, inefficiency in Search and Rescue is small.

***Effectiveness of Mitigation Options***

Although the GESI Pilot Project used the GHI method to compare the effectiveness of a standard set of potential mitigation actions in each city, it did not generate suggestions suitable for formulating public policy. For this part of the method to be useful, local experts should be the ones to suggest and evaluate the mitigation options. These results are meant only to demonstrate how the GHI method can be used to evaluate the effectiveness of mitigation options.

Figure 11 shows the effectiveness in San Salvador and Delhi of four hypothetical mitigation options. The following definitions were adopted to calculate these results:

- "All new buildings are well-built for 10 years," means that all new buildings of a given construction type are constructed to the best possible standards for that type.
- "Worst 5% of buildings are replaced," means that the most vulnerable 5% of the buildings are removed.
- "Improved Medical Preparedness," means that the city achieves a perfect score in Medical Care Capacity.

- "All new buildings are sited safely for 10 years," means that all new development is built away from landslide areas and engineered to withstand the amplified shaking on soft soil.

In all cases, the definitions listed above were applied one at a time, assuming that all the other factors remained unchanged, ignoring any possible synergies or inefficiencies that might occur if several improvements were made at once.

The risk mitigation analysis presented in Figure 11 indicates that, among the options considered, the most effective means of reducing risk in San Salvador is to site buildings safely for ten years, avoiding landslide prone areas, while, on the other hand, for the city of Delhi, constructing buildings well for ten years and improving medical preparedness are the most effective.

***Results for schools***

Figure 12 shows the per capita school earthquake lethality potential for those GESI Pilot Project cities that had complete data about schools. School results were calculated using only information about primary public schools, in particular, about their construction and student population. School buildings were assumed to be evenly distributed across the cities.

According to the preliminary results, a school child in Kathmandu is 400 times more likely to be killed by an earthquake than a school child in Kobe and 30 times more likely than a school child in Tashkent. In Latin America, a school child in Mexicali is 1.5 times more likely to be killed by an earthquake than a school child in Quito and about 30 times more likely than a school child in Antofagasta.

Comparisons like these are intended to provoke the public and local governments to consider whether their schools' risk and, in general, their city's risk, are acceptable. If the risks are unacceptable, the GHI method can suggest effective risk mitigation actions.

## Results Dissemination and Review

The preliminary results for both cities and schools were sent to the participating cities, in the form of City Risk Reports, for corrections and comments. The City Risk Reports presented the results in various forms. In addition to the results described previously, results in the City Risk Reports compared the cities in terms of Hazard, Building Vulnerability and Response Preparedness. Hazard was defined as the peak ground acceleration (PGA) with a 10% probability of being exceeded in 50 years averaged over the whole city, taking into account the amplification due to soft soils. Building

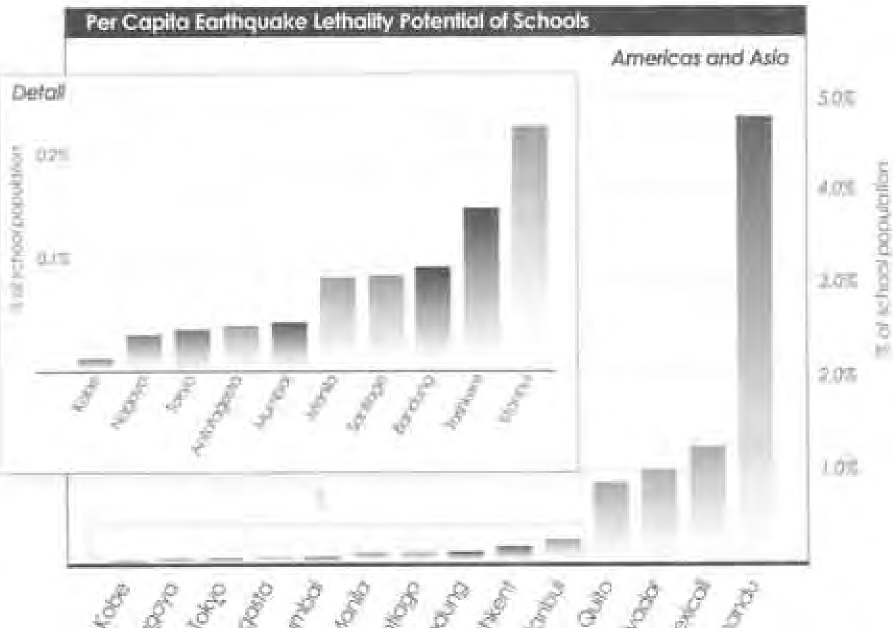



Fig.12 Comparison of the per capita school earthquake lethality potential in the GESI pilot cities. Cities are classified by per capita GNP (red: over USD 10,000; green: between USD 1,000 and 10,000; and blue: under USD 1,000). For clarity, the results for the cities with lower per capita school earthquake lethality potentials are shown in the detail graph. According to these preliminary results, a school child in Kathmandu is 400 times more likely to be killed by an earthquake than a school child in Kobe and 30 times more likely than a school child in Tashkent.

vulnerability looked at the lethality of the building stock in each city, holding hazard constant. Response Preparedness was a combination of the Emergency Response Capacity and the Medical Emergency Response scores.

Appendix 4 presents, as an example, the City Risk Report sent to Antofagasta.

The review of the preliminary results had the additional benefit of helping people in the participating cities prepare for the evaluation phase of the GESI Pilot Project.

### Method Validation

Validating the GHI method is difficult, especially in an eighteen-month project. GHI attempted to validate the adopted model in the two ways described below.

#### *Independent Expert Assessment of Cities' Risk*

While the algorithm was being developed, GHI applied its method, using library data, to ten cities and compared those results with the independent assessment of those same cities by an earthquake expert. The expert did this by researching the consequences of past earthquakes in these cities and using his knowledge of the cities' current conditions to estimate what the consequences would be of earthquakes today. He did not know the results of using the GHI method. Nonetheless, his relative ranks of those cities' risks were remarkably similar to the GHI method's results; cities never varied more than two positions between the two rankings and were usually much closer than that. There was greater variation between the rankings of per capita life loss, but only one city was offset more than two positions between the rankings, and again most cities matched closely. In short, the proposed method produces results that an expert would find reasonable.

#### *El Salvador Post-earthquake Visit*

On January 13, 2001, a magnitude 7.6 earthquake struck El Salvador affecting, among other cities, its capital, San Salvador, one of the GESI pilot cities. The earthquake caused more than 800 deaths. One month later, on February 13, 2001, a second earthquake hit El Salvador affecting San Salvador again. This second event had a magnitude of 6.6 and caused more than 300 deaths.

Two weeks after the January 13 earthquake, members of the GESI Team visited the affected area to compare San Salvador's actual earthquake damage to the results of using the GHI method. San Salvador's City Team leaders arranged field observations and interviews with a number of local organizations and individuals, many of whom were directly involved in the implementation of the GESI Pilot Project in San Salvador.

The comparison indicated that the GHI method produced reasonably accurate results. Because the method's results are best regarded as an average or expected value, the life losses caused by both the January 13 and February 13 earthquakes were combined. About 65% of the combined life losses for the two events were caused by earthquake-induced landslides, 35% were caused by building collapse, and there were no victims from earthquake-induced fires. This compared well with the results of the GHI method, which attributed 55% of the earthquake risk in San Salvador to earthquake-induced landslides, 45% to building collapse, and 0% to earthquake-induced fires.

Since the GHI measure represents composite losses, it does not make sense to compare its results with the damage caused by a specific event. Over time, however, it should be possible not only to validate but also to improve the method by comparing its results with observed events.

Table 1 Comparison of the actual sources of life loss in San Salvador's earthquakes on January 13 and February 13, 2001 to those identified by the GESI Pilot Project.

**Sources of Risk in San Salvador**

| | Earthquake-Induced Landslides | Building Collapse | Earthquake-Induced Fires | Total |
|---|---|---|---|---|
| Predicted | 55% | 45% | 0% | 100% |
| Observed | 65% | 35% | 0% | 100% |

## Project Evaluation

The GESI Pilot Project evaluated the GHI method by conducting two workshops in early 2001. One (for representatives from the Asian cities) was held in Kobe, Japan on January 29-31, and another (for the American cities) in Quito, Ecuador on March 5-7. Local and international technical experts, city officials, and representatives from international agencies were invited to participate.

The evaluation workshops had three specific objectives:

- To determine the usefulness of the results to cities and international development organizations,
- To suggest improvements to the data collection and results dissemination processes, and
- To recommend follow-up actions.

For each workshop, participants were divided into three working groups based on their involvement with the project and their technical background. The first group comprised city representatives who had worked with the GESI team to collect data, together with city officials who would be implementing the suggested mitigation actions. The second working group included representatives from international agencies including the Office of U.S. Foreign Disaster Assistance (OFDA), the United Nations Centre for Regional Development (UNCRD), the United Nations International Strategy for Disaster Reduction (ISDR), and the World Health Organization (WHO). The third group consisted of technical experts, professors and scientists in the fields of engineering, seismology, and disaster management. In all, there were about 40 invited participants and 30 observers in each workshop.

The evaluation of the GHI method was divided into three topics, *Results*, *Process*, and *Future*. Each working group discussed each topic for an hour and a half, and then a reporter from each group summarized the group's findings in a plenary session, which led into an hour-long plenary discussion. At the end of each plenary discussion, a moderator reviewed the major points and ideas generated. In the last session of the workshop, which was a plenary session, a summary of each session was presented for review, to ensure that the conclusions of each session accurately represented the consensus of the participants.

The two evaluation workshops came to many similar conclusions. Concerning the results, both groups thought that the GHI method produced reasonable results, that the data needed to be verified before results were used to determine public policy, and that the results needed to be targeted to different audiences, including the lay public, business leaders, and government officials. Concerning the implementation, the two groups thought that GESI should involve as many local institutions as possible in all of its aspects to increase local feelings of ownership of the results. They also believed that the separate analysis of schools was valuable. Regarding future activities, participants of the two workshops agreed that the GHI method had the potential to motivate action, that it should continue to be applied around the world, and that separate studies of hospitals should be conducted.

While both groups indicated their overall approval of GESI and its direction, the discussions in the two workshops offered different perspectives on some aspects of the implementation. The Kobe Evaluation Workshop participants were most concerned that the project should expand to many more cities as rapidly as possible. They indicated that city data should be updated periodically to track changes in risk and risk mitigation efforts. They also thought that GHI should form partnerships with local non-governmental organizations in order to expand the influence of the project and encourage local implementation.

The participants of the Quito Evaluation Workshop liked the project's focus on prevention and planning. They indicated that risk mitigation should be emphasized starting as early as the data collection. This group thought that familiarizing local people with the data collection and the methodology would help publicize the project. International organizations could coordinate and support such local efforts. Some participants were concerned that measurements of life loss alone would not motivate action, and that socio-economic indicators should be included as well. Most agreed that the methodology and results needed to be better validated before many more cities were added, and that it was essential to develop a general process for disseminating the results in the cities.

Detailed summaries of the two workshops are given in Appendix 5.

## Discussion

Implementing the GESI Pilot Project in twenty-one cities with the help of hundreds of people around the world raised several issues. The most significant of these are discussed in this section.

### Data

There were two main concerns about the data: the accuracy of the data within a city and the consistency among cities. The data reflected many discrepancies between official and unofficial sources, and in all cases the GESI Team decided to use the information that seemed to most closely represent the situation, regardless of whether it was sanctioned as 'official'. In an attempt to improve the accuracy of the data, the GESI Team sent the selected data back to the cities for comments and corrections. Several cities responded with modifications, some of which are reflected in the preliminary results presented in this report.

To allow direct comparison among cities, the questionnaires were designed to solicit well-defined, uniform, and quantitative information. Nonetheless, some of the indicators contain subjective elements. Efforts were made to ensure that the data collectors used the same criteria when making subjective decisions, but it was not possible to completely remove the effect of personal opinion. In the future, objective proxies will be sought to replace indicators that are presently subjective.

### Participation

Twenty-two cities were asked to participate in the GESI Pilot Project, and all but one assembled the necessary data in a timely manner, even though all the local work was voluntary. This seems to indicate the cities' strong interest in understanding the magnitude, characteristics, causes, and possible management solutions of their earthquake risk.

It was not possible to collect all the school data in all of the cities; only fourteen of the cities completed the school data sets. There may be several reasons for this difficulty. The focus on a single system seemed to have two consequences:

- It limited the sources of information to, in most cases, only one organization, the one in charge of administering the school system. When that organization was well organized and willing to participate, school data were made available. When that was not the case, it was very difficult, if not impossible, to find an alternate source of information.
- It gave the impression that very precise information was required. Since one specific system was being evaluated, and possibly "judged" both locally and internationally, people did not feel comfortable providing information that they felt did not completely reflect the local reality.

Some of these difficulties may also arise if the method is extended to other specific systems such as hospitals or water supply.

## Chapter 4

# CONCLUSIONS

## Method

ONE of the purposes of the GESI Pilot Project was to evaluate the GHI method of assessing community earthquake safety. In particular, GESI sought to determine if this method was useful, defensible and understandable, and how it should be developed in the future.

### Useful

The GHI method produces results that are useful in several ways. First, they raise awareness of earthquake risk. They identify sources of risk and their relative importance. When used by a local risk manager who is familiar with the city, the method can evaluate the effectiveness of mitigation options (e.g., improved disaster planning, medical response, search and rescue, and building and land-use codes), and compare their costs and benefits to those of other city programs. It can track changes in the world's urban earthquake risk. It can help set national and international funding priorities, based on need and effectiveness. Finally, when the results of several cities are compiled, the method can be used to compare the relative life-loss risk these cities face. In sum, these uses of the method can improve risk management and may motivate local action.

### Defensible

The GHI method was reviewed by the Project Advisory Committee who oversaw its development and also by a large and diverse collection of international earthquake experts who were convened in the two evaluation workshops. Each of these groups considered the method to be sound and its characterization of the earthquake risk of a wide variety of cities reasonable. A paper is now being prepared for submission to a peer-reviewed journal to seek further expert critique.

### Understandable

A wide range of professionals, from many countries, understood the method's results and perceived them to be relevant.

### Future

The method should be continually improved. New methods must be developed to ensure the high quality and uniform interpretations of the data from city to city. There will be improvements to the algorithm itself as experience is gained from earthquakes in the cities whose risk has been assessed. In addition, the method can be expanded beyond the risk of life loss from earthquakes. Suggestions have included estimating economic losses and evaluating hazards other than earthquakes. The presentation of the results, also, should be continually improved, in order to make them more easily understood. For example, they should be targeted to particular audiences and focused on mitigation.

## Application

The second purpose of this project was to evaluate the application of the GHI method. In particular, the purpose was to study GESI's potential—to raise public awareness, to evaluate mitigation options, and to improve earthquake risk management globally—as well as to recommend how it should be used in the future.

### Potential to Raise Public Awareness

GESI has already raised public awareness. The preliminary results of the GESI Pilot Project attracted media attention, resulting in articles and TV interviews in Chile, Ecuador, El Salvador, Japan, Mexico, and the US. The extremely high relative risk of Kathmandu attracted particular attention in that community and triggered meetings of Nepalese officials, diplomats of the foreign embassies resident in Kathmandu, and the international organizations operating there. At this writing, the outcome of these meetings is not known, but there is no doubt that the GESI results raised awareness in Kathmandu of the risk there. The full potential of GESI in this regard, however, has not been tested, because the GESI Pilot Project did not attempt to publicize its results widely or systematically.

### Potential to Evaluate Mitigation Options

Although the Pilot Project did not afford an opportunity to evaluate this fully, GESI could be used to propose risk mitigation options to a community, based on the community's sources of risk and growth patterns. Such a proposal would require the involvement of people intimately familiar with the development plans of the community and could include an estimate of the expected costs of the various mitigation options. The city could use this information to compare the costs and benefits of earthquake mitigation with those of other contemplated public programs.

### Potential to Improve Earthquake Risk Management

GESI has the potential to improve earthquake risk management worldwide. In each community where it is conducted, GESI draws together a multidisciplinary group of people responsible for earthquake risk management and provides them with a framework for discussing the various sources of risk and the various means of mitigating it. Such a discussion begins uncovering gaps in knowledge and preparedness. In some GESI pilot communities, the risk managers had never even met each other before being involved in GESI. In one city, the emergency response community realized that the agency believed to have developed an emergency response plan, in fact, had not. While the Pilot Project was too brief to evaluate systematically GESI's potential to motivate risk mitigation, it suggested that this potential exists. For example, the Pilot Project inspired one city to improve its building code. Another city's leaders drew upon the GESI Pilot Project results in thinking about how to better attract foreign investment.

Twenty-one of the twenty-two communities invited to participate in the GESI Pilot Project accepted, donating an average of two person-months of labor to collect the data, review the results, and evaluate the Pilot Project. Some cities invested an order of magnitude more effort, perceiving it to be in their self-interest. Participants urged that the preliminary results be made final, and that they be formally disseminated. Several cities that were not part of the Pilot Project learned of GESI and asked to be included in the future. This willingness of local risk managers to contribute their own resources to GESI is a measure of its potential to improve risk management.

### Future

Based on GESI's formal evaluations and the response it has received, we conclude that GESI should be applied to hundreds of the world's most earthquake-threatened communities. These should include cities and "catchment" areas, selected according to criteria including their earthquake hazard, population, and economic, cultural and political importance. GESI should be applied to each of these communities periodically, perhaps once every four years. While local specialists in each community will play leading roles in collecting data, an international organization, such as GHI, should ensure a high and uniform standard of analysis so as to allow inter-city comparisons. The results should be released in each community by the local specialists who gathered the data, as well as internationally, for example, at a UN-sponsored conference. The release of GESI results should be accompanied by a report on each community's progress towards self-assigned mitigation goals, and by an announcement of each community's goals for the future. Such a report would encourage comparison, collaboration and competition among cities. This program should be started in a few regions and gradually spread globally.

## Closing Remarks

Because earthquake disasters such as those that recently occurred in India and El Salvador are manmade, not natural, humans can reduce their effects. As people come to see earthquake disasters as their responsibility, they will seek means to manage them. GHI developed the method evaluated in the GESI Pilot Project in the hopes that it would be applied in earthquake-threatened cities around the world, so that their risks would be known, their most effective means of mitigation identified, and their inhabitants motivated to question the acceptability of living with such risk. Thanks to the generosity of the hundreds of people and organizations that made this project possible, GHI and UNCRD have demonstrated the promise of this method. The continuity of GESI is essential. With the continued involvement of the participants of the Pilot Project and the collaboration of new partners in the future, GESI can be used to improve earthquake risk management worldwide.

# REFERENCES


Cardona, C., R. Davidson, and C. Villacís. "Understanding Urban Seismic Risk around the World: A Comparative Study of the RADIUS Initiative." *RADIUS: Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters.* Geneva, Switzerland: IDNDR Secretariat, United Nations, 2000.

Davidson, R. *An Urban Earthquake Disaster Risk Index.* Stanford, CA: Stanford University, 1997.

Labat-Anderson. *Disaster History: Significant Data on Major Disasters Worldwide, 1900-Present.* Report prepared for the Office of U.S. Foreign Disaster Assistance, Agency for International Development, Washington DC 20523, USA, 1991.

Tucker, B., G. Trumbull, and S. Wyss. "Some Remarks Concerning Worldwide Urban Earthquake Hazard and Earthquake Hazard Mitigation." In *Issues in Urban Earthquake Risk*, edited by B. E. Tucker *et al.* Dordrecht, Netherlands: Kluwer Academic Publishers, 1994.

Villacís, C., and C. Cardona. "Case Studies in Latin America." *RADIUS: Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters.* Geneva, Switzerland: IDNDR Secretariat, United Nations, 2000.

**Appendix 1**

# Summary of the Project Advisory Committee Meetings

## April 1, 1999 Meeting

THE first Project Advisory Committee (PAC) meeting focused on the overall goals of the GHI method to assess community earthquake safety, and how these goals can best be achieved. The committee believed that in keeping with the mission of GHI, the method should aim to reduce life loss rather than economic loss. It should be motivational, emphasizing the possibility of future safety rather than present hazard; in particular, it should present inexpensive risk mitigation options. The PAC thought that it was important that all aspects of the method be transparent and that the committee eventually be expanded to include international representatives.

The discussion of data collection compared the benefits of three modes of obtaining data: library research, questionnaires that experts in the cities would fill out and return, and interviews in the participating cities. For most committee members, the third option was the most attractive because it would produce the most accurate and credible results. It was suggested that the results and input data be sent to the cities for comment and review, before they were released publicly. There was also interest in collecting information about the cities' current risk management activities, but it was thought that this information would be difficult to gather in light of how diffuse the responsibility for such activities often is.

With regard to the project's ability to both clarify international earthquake risk and motivate mitigation, the committee thought that it would be useful to compare similar cities, either in terms of size or socio-economic situation, and to report the rate of change of risk instead of the total risk. The PAC indicated that because the world is experiencing a significant population increase, possibly doubling in the next 25 years, the GHI method is poised to have a large impact. For this reason, the consensus of the group was to continue with the method development and to complete it as quickly as possible. The committee thought that the method should not languish while it was being perfected, but should be fine-tuned continuously. The committee saw the method raising world awareness about earthquake risk and in doing so, compelling and helping policy makers such as the World Bank, the Asian Development Bank and local governments to make decisions that reduce risk instead of increase it.

## July 1, 1999 Meeting

The second Project Advisory Committee meeting focused on the algorithm that would form the basis for the GHI method and on the method's prospects for motivating decision makers. It was noted that because earthquakes are only one of many problems facing cities, the method should present different mitigation options to help leaders make informed choices about how to use their limited resources. A loss-estimation alone would provide insufficient information to support such choices. Committee members thought it would be more motivational to project changes in the number of lives at risk than to estimate changes in risk management efforts over time. More generally, the method must be transparent, applicable to any city and endorsed by experts if it is to be widely accepted. The PAC stressed the importance of keeping the participating cities involved in the project, both to maintain credibility and to instill a sense of ownership.

It was suggested that before a loss-estimation model is adopted, it would be wise to explore other models. There was some concern that by adopting a loss-estimation model, GHI would seem to be competing with some for-profit companies. In addition, by virtue of its transparency and its basis in well-understood (scientific and financial) relationships, the loss-estimation model would be more open to criticism than a more frankly subjective approach. An option presented was to create a dimensionless index, and compare its results with those of the loss-estimation model for 10 sample cities. The arguments in favor of the dimensionless index were that it would be easier to construct and that subjective or indirect indicators could be more easily combined than a traditional loss-estimation. However, without measuring tangible effects, the dimensionless method would be unlikely to encourage mitigation. It was also pointed out that the GHI method differs from other loss-estimations in its focus on cities as a whole, instead of individual (insured) buildings; cities will also perceive it differently because of GHI's non-profit status.

The PAC thought that forecasting mitigation using both models would help GHI choose between the models. The test sample should include both large and small cities, rich and poor cities, and cities with significant and negligible earthquake hazard. It was also suggested that cities with easily accessible data be chosen. The committee revisited the question of international review, concluding that it should occur only after the project framework is firm, but while modification is still occurring.

## November 22, 1999 Meeting

The third Project Advisory Committee meeting centered on what method GHI should employ and how the pilot project should be implemented. Three possible methodologies were presented for discussion: one was based on loss-estimation and the other two generated dimensionless indices, one based on a set of discriminating questions and one based on Rachel Davidson's Earthquake Risk Disaster Index (EDRI).

Many committee members indicated that it was less important to rank the cities according to some optimal definition of risk than to provide a ranking that proved effective at motivating action. The most motivational method would be one that was simple, transparent, easy to modify, and able to track changes in risk over time. It was argued that it would be better to use a slightly more complex method that reflected mitigation than a simpler one that did not; however, everyone agreed that the method chosen must be comprehensible to non-technical people. The group reaffirmed that GHI's goal should be a defensible, internationally reviewed risk assessment of life loss. It did not seem worthwhile to create an economic loss-estimation model, which would be likely to divert attention from life loss, have less impact and be so complex as to be difficult to defend.

The group consensus was that the method should be implemented quickly, not waiting for the final revisions of the method. Committee members were concerned that it would be hard to obtain good data in every city, and they agreed that city visits would be necessary. These visits would also provide a chance to start raising awareness about risk management.

The PAC thought that the results should be tailored for each city, including short- and long-term mitigation options and some information on their costs. There was debate on whether the results should be disaggregated to show the factors contributing to each city's risk, which would increase their usefulness, but might imply an unrealistic level of precision.

The PAC recommended several long-term goals for the project team, such as submitting a paper on the GHI method, and expanding to many more cities (~300). It was also recommended that GHI incorporate its method into a long-term plan of working with cities to directly reduce risk of life loss.

## November 16, 2000 Meeting

At the fourth Project Advisory Committee meeting, the committee was shown preliminary results from applying the GHI method to twenty-one cities around the world. The committee was asked to comment on the method, results and presentation and to recommend future actions. Several international experts participated in the meeting as guests.

The group started by talking about the intended users of the project, and how the results might influence them. Some PAC guests wondered whether the project was aimed at international aid organizations or local community members, and how the presentation should change depending on the target audience. Many members questioned the value of targeting international aid organizations, thinking that the GHI method might have little or no effect on their decisions, because of their focus on post-disaster aid rather than mitigation. This concern seemed to reinforce the importance of city visits as a way of educating community members about possible risk management actions. It was thought that the target audiences among local communities should include businessmen, political leaders, and social organizations such as churches and schools.

Some of the invited guests suggested that a risk assessment made outside the cities, such as by a panel of experts, might be more cost-effective. However, these alternatives seemed to require two indices—one for risk and one for mitigation—that might be confusing. There was also concern that an assessment made remotely would alienate the local communities. While some members worried that the data collection would tax cities' resources, it was also felt that it would contribute essentially to cities' understanding of their own risk.

It was generally believed that comparisons among cities of similar economic or social standing could be strongly motivational if they highlighted threats to economic competitiveness, but that comparison between developing and industrialized cities served little purpose. Some guests revisited the idea that the results should reflect consequences other than fatalities, such as economic losses, and that the level of risk of each city should be reflected in the importance placed on risk management efforts.

As to fears that the method might be criticized for its assumptions or complexity, committee members indicated that it was more important for the results to be reasonable, consistent, reproducible and understandable than precise. Most of the users would be scientifically unsophisticated and therefore less likely than the PAC to criticize the results on technical grounds. The committee suggested that efforts be made to ensure that the results are properly interpreted, and not taken to mean more than they do. They also indicated that validation of the results and data would be important steps, and suggested using the regional workshops, recent earthquakes and expert comparisons to accomplish this. In the future, to avoid issues concerning conflicting data, it was suggested that GHI take responsibility for the data and present it without reference to the local source, which would allow the results to be independent and objective.

The Project Advisory Committee indicated that it still fully supported the project, and that GHI should continue with GESI, improving the method continuously, and working towards a full-scale application soon. The committee suggested that it would be essential to evaluate the method's ability to motivate action, but believed that it was too soon for such an assessment to be meaningful.

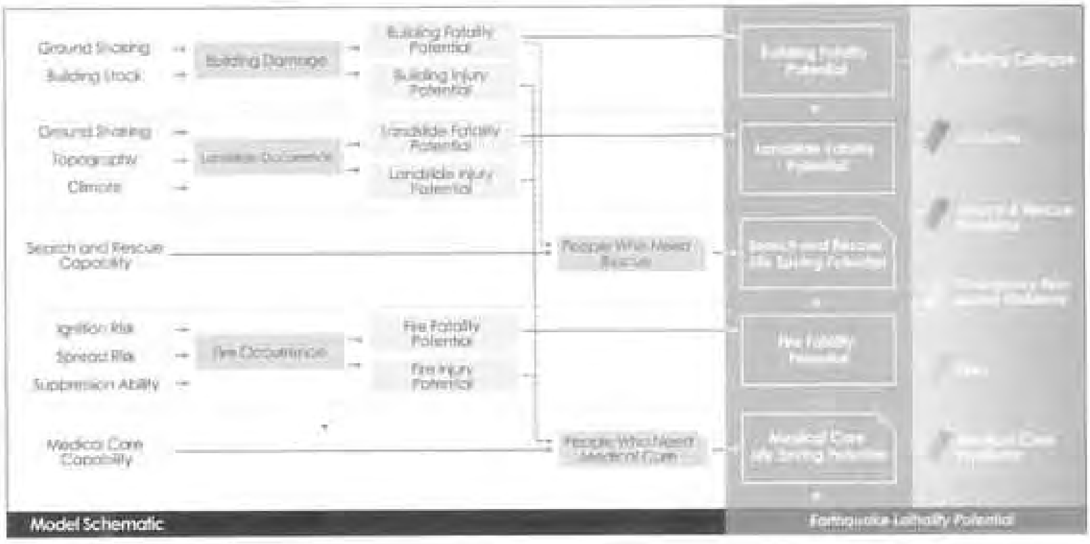
## Appendix 2

# Technical Description of the GHI Method

THIS appendix provides an overview of the technical details of the GHI method.

The method outlined below produces results that compare the risk and risk management of cities. Although it parallels loss estimation in many ways, it contains simplifications that would be undesirable in true loss estimation.

We expect that the method we describe below will evolve through further research and through application to more and more cities around the world. Figure 1 outlines the basic concept of the method. To help the reader understand it better, the shaded boxes throughout the discussion calculate the steps for an imaginary city, "GESIville".



## Step 1: Measure ground shaking

One standard measure of an earthquake's strength is the peak horizontal ground acceleration (PGA) experienced during it. To compare cities' differing susceptibilities to large earthquakes, we assign each city a PGA value corresponding to the PGA with a 10% probability of being exceeded in 50 years, or, equivalently, the PGA whose return time is 475 years. Henceforth the acronym PGA will mean this particular point in the distribution of accelerations that a city might experience. Many cities, such as those traversed by faults, encompass areas with widely varying distributions of ground accelerations. We assign such cities the average 475-year PGAs over their areas. Throughout the model, PGA is expressed in terms of percent of gravity (%g).

In a scenario analysis, the use of a single ground acceleration for a whole city would correspond to the assumption of uniform shaking on all firm ground sites, something that would be unlikely to occur in any individual earthquake. On the other hand, most loss estimations would integrate the losses expected from the whole distribution of possible earthquakes, rather than picking those associated with a specific return period. Instead of assessing the consequences of single "scenario" events or of averages of such events, we consider the probable maximum shaking each part of a city is expected to experience in a 475-year period, even though different parts of the city might experience this shaking in different earthquakes.

We use PGA to measure ground shaking because it can be obtained rather reliably worldwide. On its own, it is not always a good predictor of damage, but more sophisticated measures are not available worldwide. The other readily available information about ground shaking, the Modified Mercalli Intensity (MMI), is subjective and possibly inconsistent among different parts of the world.

**GESIVILLE: Step 1**

PGA with 10% probability of exceedance in 50 years = **30%g (0.3g)**

## Step 2: Measure the amount of soft soil in the city

Because shaking is amplified on soft soil, it is necessary to estimate how much of each city is built on soft soil. We define soft soils as those with an average shear wave velocity less than or equal to 180 meters per second in the upper 30 meters. This definition corresponds to soil types E and F in the 1997 NEHRP Provisions (NIBS, p 4-21).

Soil information is available in varying detail around the world. Many cities' subsurface geology has never been well characterized, and even among those cities for which some subsurface information is available, few have maps showing shear wave velocities over their entire areas. To estimate the amounts of soft soil in each city, we combine all available technical soil information with more general information locating flood plains and man-made land. Table 1 shows guidelines that were given to local specialists to help classify soils.

**Table 1: Soil Classifications**

| | |
|---|---|
| **Soft Soils** | Loose submerged fills, very soft to soft clays, liquefiable soils, quick and highly sensitive clays, peats, highly organic clays |
| **Firm Ground** | Metamorphic rocks, granites, igneous rocks, conglomerates, sandstones, shales, gravels, soils with > 20% gravel, loose to very dense sands, silt loams, sandy clays, medium stiff to hard clays |

(taken from Davidson, 1997 [illegible])

For the purposes of estimating the risk of building damage, we assign the portion of the city on soft soil a PGA equal to 1.5 times that on firm ground. We use this same multiplier for all cities, even those for which detailed soil studies are available. In reality, different soils amplify ground motion differently and have different resonant frequencies. The amount of amplification therefore depends not only on the soil type but also on the period of the earthquake experienced, but these dependencies are not included in the model.

**GESIVILLE: Step 2**

Shaking on soft soil = **1.5 * 0.3 = 45%g (0.45g)**
Percent of city area with soft soil = **40%**

**Sources:**


1. Davidson, Rachel. "Earthquake Risk Information Worksheets, Document E." GeoHazards International; Understanding Urban Seismic Risk Around the World Program of the UN-IDNDR RADIUS Project, 1999.
2. Earthquake Engineering Research Institute. Reducing Earthquake Hazards: Lessons Learned from Earthquakes. EERI, 1986.
3. National Institute of Building Sciences (NIBS), HAZUS Technical Manual. Federal Emergency Management Agency, 1997. Volume I, pp. 4-1 to 4-50 and 6-1 to 6-35.


## Step 3: Measure building attributes

Building vulnerability is critical to earthquake risk. Collapsed buildings caused about three quarters of all earthquake fatalities during the 20th century (Coburn *et al.*), and they continue to form the bulk of the earthquake risk in most cities of the world. For the model to be meaningful, it must measure building quality around the world accurately enough to differentiate cities' risks, but it cannot afford to become unworkably complex. Unfortunately, information about building stock around the world is extremely limited, and generating it is costly. The approach outlined below was designed to balance the need for such information against its costs.

To characterize a city's buildings, we asked local specialists to list the key building types and to estimate how much of the total building stock each type represented. We compared this information with any available published studies and with the observations we made during our own visit.

We use a four-step process to characterize the vulnerability of the cities' buildings. First, each structural type is assigned to one of the following broad categories:

1. Wood
2. Steel
3. Reinforced concrete
4. Reinforced concrete or steel with unreinforced masonry infill walls
5. Reinforced masonry
6. Unreinforced masonry (fired brick, concrete block and shaped stone)
7. Adobe and adobe brick
8. Stone rubble
9. Lightweight shack (e.g. corrugated iron sheet) or lightweight traditional (e.g. bamboo)

Because each category includes buildings that vary significantly in the quality of design, construction, and materials—and therefore in the ability to withstand shaking—the second step rates each building type according to these characteristics, as shown in Table 2.

**Table 2: Rating Scheme**

**Quality of design**

| | |
|---|---|
| 0 | Engineered with seismic design |
| 1 | Engineered without seismic design, or non-engineered using seismic resistant rules of thumb (e.g. lintel band for masonry) |
| 2 | Non-engineered, no seismic resistant elements, good proportions (short, wide, symmetric) |
| 3 | Non-engineered, no seismic resistant elements, poor proportions (tall, narrow, or non-symmetric) |

**Quality of construction**

| | |
|---|---|
| 0 | Excellent quality, effective supervision of seismic elements of construction |
| 1 | Good quality, some supervision of seismic elements of construction |
| 2 | Moderate quality, no supervision of seismic elements of construction but skilled workers |
| 3 | Poor quality, no supervision and unskilled workers |

**Quality of materials**

| | |
|---|---|
| 0 | Good quality materials |
| 1 | Poor quality materials, or poor maintenance of building |

Third, the ratings for design, construction and materials are summed and each type is assigned one of the model's nine standard vulnerability ratings, *A* through *I*, as indicated in Table 3. *A* represents the highest earthquake resistance and *I* the lowest.

**Table 3: Vulnerability Curve Assignments**

| *Building Types* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* |
|---|---|---|---|---|---|---|---|---|
| Wood | A | A | B | B | C | C | C | D |
| Steel | A | B | C | C | D | D | E | F |
| R/C | B | C | D | E | E | F | G | H |
| R/C, steel infill | C | D | D | E | E | F | G | H |
| Reinforced masonry | C | D | D | E | E | F | F | F |
| URM | E | E | F | F | G | G | G | H |
| Adobe | N/A | N/A | G | H | H | H | H | I |
| Stone rubble | N/A | N/A | G | H | H | H | H | I |
| Lightweight shack | N/A | N/A | N/A | H | H | H | H | I |

Numerous studies of building vulnerability delimit the range of responses typical of each structural type and illuminate the importance of design, construction and material quality in determining where in that range any particular building's experience will lie. Nonetheless, we had to make many assumptions to complete Table 3, and we neglected any consideration of the natural periods of the buildings.

We developed vulnerability curves for the nine categories to cover more or less evenly the range of ways that buildings respond to earthquakes. The nine vulnerability curves are shown in Chart 1. Unfortunately, different vulnerability studies measure damage differently. Most estimate the ratio of the dollar value of a building's damage to its replacement value, as a function of ground shaking; a few consider the completeness of collapse; and others use still other measures such as "percent of buildings damaged". It is not easy to compare the results of these studies or to translate their measurements into implications for life loss. Most deaths would be clustered in the highest damage categories of these economic scales. Knowing that a building's damage corresponded to 100% of its replacement value still leaves great uncertainty about how many of its occupants were killed. As a result, our damage curves extrapolate those of most studies to differentiate levels of collapse that might be economically equivalent but have very different human consequences.

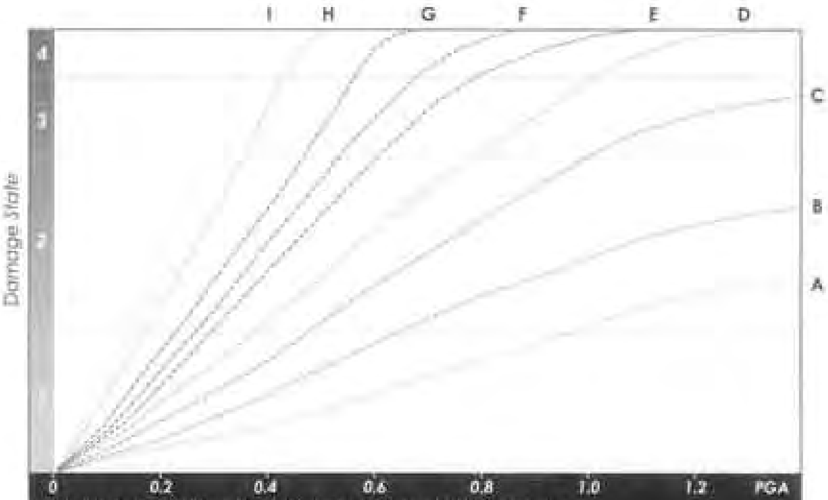


Chart 1: GESI Standard Building Vulnerability Curves

Chart 1 shows the average damage state of a building at a given PGA. We define four states of damage: (1) none, slight or moderate; (2) extensive; (3) partial collapse; and (4) complete collapse. These damage states were adapted from those used by HAZUS. HAZUS's none, slight and moderate categories were combined into one GESI category because casualties are rare in these damage states. The complete damage state was divided into two categories, partial collapse and complete collapse, to account for the large range of possible life loss in this state. See Table 4 for an explanation of these damage states.

**Table 4: GESI Building Damage States**

| Damage State | Description |
|---|---|
| 1. None, slight or moderate | Ranging from no damage to non-structural damage and minor structural damage. |
| 2. Extensive | Extensive structural and non-structural damage. Localized life-threatening situations are common. |
| 3. Partial collapse | Building is entirely structurally compromised and on the verge of collapse or small portions of the building have collapsed. |
| 4. Complete collapse | Building is entirely destroyed, with significant portions of the building collapsed. |

Finally, the percent of the total building stock represented by each building type is estimated, along with the typical height, classified as low-rise (one to three stories), medium-rise (four to seven stories) or high-rise (eight or more stories). If a building type covers more than one height category, these are divided into separate types in the analysis. Each building type is further classified as heavy and non-ductile, light and/or ductile, or extremely light (e.g. CGI sheet). Wood and steel buildings and some low-rise constructions with light roofs usually fall into the light and/or ductile category and tend to cause fewer deaths. All other types are classified as heavy and non-ductile.

**GESIVILLE: Step 3**

| Building Types | Design Rating | Constr. Rating | Materials Rating | Vuln. Curve | % Bldgs | Height | Weight |
|---|---|---|---|---|---|---|---|
| Wood | 1 | 1 | 0 | B | 70% | Low | Light/Ductile |
| R/C infill - med ht. | 1 | 1 | 0 | D | 15% | Med | Heavy/ Non-ductile |
| R/C infill - high ht. | 1 | - 1 | 0 | D | 5% | High | Heavy/ Non-ductile |
| URM | 2 | 3 | 0 | G | 10% | Low | Heavy/ Non-ductile |

Sources:


1. Applied Technology Council. ATC-13: Earthquake Damage Evaluation Data for California. ATC, 1985.
2. Beca Worley International Consultants. The Development of Alternative Building Materials and Technologies for Nepal: Appendix C, Seismic Vulnerability Analyses. UNDP/UNCHS (Habitat) Subproject 88/054/21.03, 1994.
3. Building Materials and Technology Promotion Council. Vulnerability Atlas of India. BMPTC, 1997.
4. Coburn et al. "Factors Determining Human Casualty Levels in Earthquakes: Mortality Prediction in Building Collapse." Proceedings of the Tenth World Conference on Earthquake Engineering. 1992, pp. 5989 – 5994.
5. Escuela Politécnica Nacional *et al.* The Quito, Ecuador, Earthquake Risk Management Project. GeoHazards International, 1994.
6. Municipality of Guayaquil *et al.* RADIUS Project of Guayaquil. United Nations IDNDR Secretariat, 2000.
7. National Institute of Building Sciences (NIBS), HAZUS Technical Manual. Federal Emergency Management Agency, 1997. Volume I, pp. 5-1 to 6-35.
8. National Society for Earthquake Technology – Nepal. Kathmandu Valley School Earthquake Safety Program. NSET, 2000.
9. Sauter, F. and H. C. Shah, "Studies on Earthquake Insurance." Proceedings of the Central American Conference on Earthquake Engineering. Vol. II. San Salvador, El Salvador, 1978.
10. Tavakoli, Behrooz and Shahab Tavakoli. "Estimating the Vulnerability and Loss Functions of Residential Buildings." Hazards. The International Society for the Prevention and Mitigation of Natural Hazards, Vol. 7, No. 2, March 1993, pp. 155 – 171.
11. Webster, Frederick and E. Leroy Tolles. "Earthquake Damage to Historic and Older Adobe Buildings During the 1994 Northridge, California Earthquake." Proceedings of the 12th World Conference on Earthquake Engineering. Auckland, New Zealand, 2000, paper No. 0628.


## Step 4: Convert building information into damage states

The building vulnerability curves (chart 1) relate the PGA's buildings experience to the average damage they sustain. In reality, different buildings exposed to the same PGA will experience different amounts of damage, even if they are the same type of building. Because lethality is not linearly related to building damage, we consider a range of building damages varying around the average by up to twenty points (0 points representing no damage and 100 points representing the maximum or complete collapse and average the resulting lethalities). The corresponding ranges are listed in tables that are available upon request. Referring to these tables, one can estimate the percent of each building type in each damage state as a function of PGA. Because firm and soft soils are assigned different effective PGAs, there is a separate calculation for each of them. These are combined to get the overall contribution of each building type to each damage state.

**GESIVILLE: Step 4**

**Percent of each building type in each damage state on firm ground (PGA = 0.3g)**

| *Building Types* | *Damage State* | | | |
|---|---|---|---|---|
| | *(1)* | *(2)* | *(3)* | *(4)* |
| Wood | 99% | 1% | 0% | 0% |
| R/C infill walls - med | 72% | 28% | 0% | 0% |
| R/C infill walls - high | 72% | 28% | 0% | 0% |
| URM | 5% | 95% | 0% | 0% |

**Percent of each building type in each damage state on soft soil (PGA = 0.45g)**

| *Building Types* | *Damage State* | | | |
|---|---|---|---|---|
| | *(1)* | *(2)* | *(3)* | *(4)* |
| Wood | 93% | 7% | 0% | 0% |
| R/C infill walls - med | 32% | 68% | 0% | 0% |
| R/C infill walls - high | 32% | 68% | 0% | 0% |
| URM | 0% | 88% | 12% | 0% |

**Percent of each building type in each damage state in entire city**

| *Building Types* | *Damage State* | | | |
|---|---|---|---|---|
| | *(1)* | *(2)* | *(3)* | *(4)* |
| Wood | 97% | 3% | 0% | 0% |
| R/C infill walls - med | 56% | 44% | 0% | 0% |
| R/C infill walls - high | 56% | 44% | 0% | 0% |
| URM | 3% | 92% | 5% | 0% |

## Step 5: Convert building damage into the number of casualties caused by building collapse

The building inventory data deal only with the numbers of buildings of different types in a city. We did not collect information about the distribution of people among those buildings. To estimate the number of expected casualties, we weigh the various types of buildings according to their heights, assuming that for each person in a low-rise building, there are ten people in a medium-rise building, and fifty people in a high-rise building. These assumptions were based on daytime and nighttime occupancies in St. Louis, Missouri, USA (FEMA, Appendix B). They allow us to convert the building damage estimates into estimates of the percentage of the population exposed to different damage states.

We did not attempt to rate the deadliness of individual cities' building types but assigned standard lethality values to our structural categories. A building's lethality is defined as the percent of the occupants who would die in the event of collapse. We reviewed a number of studies of building lethality in past earthquakes. The figures vary drastically for similar types of buildings, suggesting that the individual characteristics of an earthquake have a great deal to do with lethality. However, the studies agree that buildings made of heavy, non-ductile materials such as masonry or poorly constructed reinforced concrete tend to kill more people than those made of light or ductile materials, such as wood, steel and well made reinforced concrete. We further assume that buildings made of extremely light materials, such as thatch, CGI sheets or cardboard, have an even lower lethality rate. The rates are shown in Table 5.

**Table 5: Building Lethality Rates**

| Building Type | Extensive (2) | Partial Collapse (3) | Complete Collapse (4) |
|---|---|---|---|
| Extremely light buildings (cardboard, bamboo, thatch, CGI sheet, etc.) | 0.01% | 0.10% | 1.00% |
| Light and ductile buildings (wood with light roofs, steel, ductile RC, etc.) | 0.05% | 0.50% | 5.00% |
| Heavy and non-ductile buildings (masonry, non-ductile RC, adobe, etc.) | 0.20% | 2.00% | 20.00% |

In addition to considering people killed immediately by building collapse, the measure includes a component reflecting building occupants injured severely enough to need medical care to survive. Little research has attempted to link injury rates to building type, and the few studies that exist do not differentiate between life-threatening injuries and less serious injuries. One frequently cited statistic asserts that there were about three times as many injuries (of all severities) as deaths in earthquakes in the twentieth century. We assume that the number of life-threatening injuries from building collapse equals the number of deaths. Both of these numbers are reduced by 25% to reflect the fact that not all people are indoors when earthquakes occur.

**GESIVILLE: Step 5**

**Population occupying each building type**

| Building Types | % of Bldgs | Height | % Pop Occupying |
|---|---|---|---|
| Wood | 70% | Low | 15% |
| R/C infill walls - med | 15% | Medium | 31% |
| R/C infill walls - high | 5% | High | 52% |
| URM | 10% | Low | 2% |

**Population in each building type for each damage state**

| Building Types | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Wood | 14.1% | 0.5% | 0% | 0% |
| R/C infill walls - med | 17.5% | 13.8% | 0% | 0% |
| R/C infill walls - high | 29.1% | 23.0% | 0% | 0% |
| URM | 0.1% | 1.9% | 0.1% | 0% |

**Population killed in each building type for each damage state**

| Building Types | (2) | (3) | (4) | Total |
|---|---|---|---|---|
| Wood | — | 0% | 0% | — |
| R/C infill walls - med | 0.028% | 0% | 0% | 0.028% |
| R/C infill walls - high | 0.046% | 0% | 0% | 0.046% |
| URM | 0.004% | 0.002% | 0% | 0.006% |

TOTAL KILLED: 0.080%

Number killed by buildings = **(0.080%)*(0.75) = 0.06%**
Number injured by buildings = **0.06%**

**Sources:**


1. Coburn, A. W. *et al.* "Factors Determining Human Casualty Levels in Earthquakes: Mortality Prediction in Building Collapse." Proceedings of the Tenth World Conference of Earthquake Engineering. Madrid, Spain, 1992, pp. 5989 – 5994.
2. Federal Emergency Management Agency. FEMA 192: Estimated Future Earthquake Losses for St. Louis City and County, Missouri. 1990.
3. National Institute of Building Sciences (NIBS), HAZUS Technical Manual. Federal Emergency Management Agency, 1997. Volume III, pp. 13-1 to 13-21.

4. Murakami, Hitomi *et al.* "Study on Search and Rescue Operations in the 1995 Hanshin-Awaji Earthquake – Analysis of Labor Work in Relation with Building Types." Proceedings of the 12th World Conference of Earthquake Engineering. Auckland, New Zealand, 2000, Paper No. 0272.

5. Pollander, Gregg S. and Douglas A. Rund. "Analysis of Medical Needs in Disasters Caused by Earthquake: The Need for a Uniform Injury Reporting Scheme." Disasters. Volume 13, No. 4, 1989, pp. 365 – 369.

6. Shiono, K. *et al.* "A Method for the Estimation of Earthquake Fatalities and its Applicability to the Global Macrozonation of Human Casualty Risk." Proceedings of the Fourth International Conference on Seismic Zonation. Stanford, 1991, pp. 277-284.

## Step 6: Measure other natural features relevant to landslide and fire

The model incorporates a few measures of the contributions cities' natural environments make to their susceptibilities to earthquake-induced landslides and fires. First, we measure the percentage of the city area threatened by landslides. We include in this figure areas that are steeper than fifteen degrees, known to be prone to landslides or directly threatened by such areas. Second, we use the city's annual rainfall as an indication of what portion of the landslide-threatened area is likely to experience a landslide at the 475-year PGA. We call communities with more than 60 inches of annual rain "wet", and communities with less "dry".

The natural environment factors into the fire calculation only through wind speed. For each city, we measure the annual average wind speed in km/hour. Other climate conditions, such as precipitation, humidity, or temperature, may affect fire spread, but the primary factor seems to be wind speed.

**GESIVILLE: Step 6**

Landslide prone area of city : 5%
Annual rainfall : 73 inches
Average annual wind speed : 40 km/hour

## Step 7: Measure other anthropogenic factors relevant to landslide and fire

The final piece of data in the landslide model is the population density of the landslide-prone areas of the city. In some cities, hills are high-rent districts with large houses, large lots and low population density. In other cities, hills are the location of densely packed slums. The life loss potential for these two conditions is quite different. For each city, we make an estimate of the ratio of the population density of hill areas to the population density of the city as a whole.

The fire model is influenced by many more anthropogenic factors than is the landslide model. In addition to those already described in earlier sections, the fire model measures the presence of fuel for the fire. Research supports the logical assumption that communities built of more flammable materials are at greater risk for fire spread (NIBS, p. 10-10; Miyazaki and Moriyama, p. 655). We measure the percentage of the population residing in particularly flammable, primarily wooden, homes.

The second characteristic we would like to measure is how densely the city is built up. This relates to how easily the fire can jump from one building to another and from one neighborhood to another. Unfortunately, this value is difficult to obtain for most cities. Instead, we estimate building density from population density. If a city has a large, undeveloped area within its boundaries, we calculate the population density excluding this undeveloped area.

**GESIVILLE: Step 7**

Population density of landslide-prone area : 0.75
Percent of flammable buildings : 70%
Population density : 10,000 pple/sq km

## Step 8: Convert landslide data into landslide-affected area

Few communities have undertaken the costly and difficult studies necessary to predict where earthquake-induced landslides might occur. Estimating the human consequences of such landslides is even more complex and less certain. Nonetheless, we have included earthquake-induced landslides in our model because they represent significant risks for some communities.

Our landslide model measures three characteristics of each community: the topography, the climate and the population density of landslide susceptible areas. This information is combined with the 475-year PGA to represent landslide risk. The assumptions presented in Table 6 are loosely based on the information presented in the HAZUS manual (NIBS, pp. 4-37 to 4-39) regarding slope, geologic deposits, wet or dry condition, PGA, and moment magnitude.

**Table 6: Assumed % of Susceptible Area that Experiences Landslides**

| Ground Shaking ($X_i$) | % Susceptible Area with Landslides | |
|---|---|---|
| | Wet | Dry |
| 0.1g or less | 0.1% | 0% |
| 0.2g | 4% | 0% |
| 0.3g | 8% | 0.1% |
| 0.4g | 12% | 3% |
| 0.5g | 16% | 6% |
| 0.6g or more | 20% | 9% |

We only consider the occurrence of localized landslides, ignoring the threat from slides traveling long distances.

**GESIVILLE: Step 8**

Percent of susceptible areas that actually have landslides: 8%
Percent of total city that has landslides: 5%*8% = 0.4%
Occupancy of landslide-affected area: (0.4%)*(0.75) = 0.3%

## Step 9: Convert landslide-affected area into deaths and injuries due to landslides

Our final landslide step is to combine all of the assumptions into a measure of the people killed and injured in landslides. We multiply the percent of the city susceptible to landslides by the percent of the susceptible areas which will experience slides (from Table 6) and multiply this value by the ratio of the population of the hills and the city as a whole. This is our representation of the population exposed to landslides. We consider 25% of this population to be killed by landslides and 25% to be injured, requiring medical care to survive.

**GESIVILLE: Step 9**

Population killed by landslides: (0.3%)*(0.25) = **0.075%**
Population injured by landslides: (0.3%)*(0.25) = **0.075%**

**Sources:**


1. Keefer, David K. "Landslides Caused by Earthquakes." Geological Society of America Bulletin. Volume 95, April 1984, pp. 406-421.
2. Keefer, David K. "The Susceptibility of Rock Slopes to Earthquake-Induced Failure." Bulletin of the Association of Engineering Geologists. No. 3, Sept. 1993, pp. 353 – 361.
3. National Institute of Building Sciences (NIBS), HAZUS Technical Manual. Federal Emergency Management Agency, 1997. Volume I, pp. 4-34 to 4-40.

## Step 10: Measure search and rescue capability

We include organized search and rescue in the analysis because it is commonly associated with post-earthquake response, even though it seldom saves many lives.

We assume that each rescue requires between 40 and 90 person-hours by search and rescue professionals, and that trapped people remain alive for 48 hours. Each city's emergency preparedness is rated from zero to sixteen, with zero being the best score and sixteen the worst. Cities with the best emergency preparedness are assumed to require 40 person-hours per rescue and those with the worst rating require 90. The scoring scheme is presented below:

- Is there a detailed emergency response plan in written form that covers the city? ("yes"=0, "no"=1)
- Does the plan specifically address earthquakes? ("yes"=0, "no"=1)
- Does the plan include input from a multidisciplinary group? ("yes"=0, "no"=1)
- Has the plan been revised to incorporate actual city experience or experiences of nearby cities? ("yes"=0, "no"=1)
- Are responsibilities of different agencies clear and well defined, including how local, state/provincial, and national agencies interact? ("yes"=0, "partially"=1, "no"=2)
- Is there a program to make sure all key players in the plan know their roles in the plan, the emergency procedures they must follow, and how they relate to other groups? ("yes"=0, "yes, but needs improvement"=1, "no"=2)
- Does the plan allow adequate "horizontal" communication and decision making (e.g., can low- and mid-level officials make decisions if higher officials are unavailable)? ("yes"=0, "no"=1)
- Is there an earthquake-resistant communications system? ("yes"=0, "no"=1)
- Is there an emergency command center that can be operational after an earthquake (e.g. building is safe, power and communications will function) ("yes"=0, "yes, but not sure all aspects will be operational"=1, "no"=2)
- Is there a standard building damage assessment procedure? ("yes"=0, "no"=1)
- Are there any programs to train citizens in emergency preparedness and/or to assist the official emergency response effort? ("yes"=0, "no"=1)
- Does the city conduct emergency response drills annually? ("yes"=0, "yes, but less than annually or without all organizations"=1, "no"=2)

The responses to the questions are summed and scaled linearly to assign rescue times to ratings between zero and sixteen. We take the number of trained fire fighters in each city as a guide to the number of trained professionals available for search and rescue. We assume that half of the trained fire fighters are available to be conducting search and rescue activities around the clock for the 48 hours after the earthquake before the victims die.

**GESIVILLE Step 10**

General emergency preparedness rating: 12
Time required per rescue: (3.125)*(12) + 40 = 77.5 person-hours
Number of trained fire fighters: 500
Assumed people available for search & rescue: 250

## Step 11: Convert search and rescue data into search and rescue life-saving potential

The number of rescues a city is able to make is equal to half the number of fire fighters times 48 hours divided by the estimated time per rescue, except that we stipulate that the population rescued cannot exceed half the number of deaths by building collapse and landslides.

**GESIVILLE: Step 11**

# rescued = (250 pple)*(48 hrs)/(77.5 person-hrs/rescue) = 155 rescues
Percent of population rescued = 155/2,000,000 = **0.008%**
Half of the deaths by building collapse and landslide: 0.135/2 = 0.0675%
0.008% does not exceed the constraint

## Step 12: Convert fire data into severity of fire threat

Earthquakes frequently spark fires, which can grow into conflagrations causing massive loss of life. One notable example was the great 1923 earthquake of Tokyo that ignited a fire that killed more than 100,000 people. Other earthquake-induced fires have caused great property loss but few deaths. According to Coburn *et al.*, earthquake-induced fires are responsible for about ten percent of all earthquake casualties this century. Presumably many of these deaths were concentrated in a few large events, since most earthquakes cause few, if any, fire deaths.

It is precisely the rare extreme deadliness of post-earthquake fires that makes it challenging to estimate the risk they pose. We examine three main factors for fire risk–likelihood of ignition, likelihood of spread, and fire suppression capacity.

### Likelihood of Ignition

Post-earthquake fires can be sparked in many ways, such as overturned water heaters or short-circuited wires. The potential ignition sources vary greatly from community to community, and also depend greatly on time of day and year. Wealthier countries may have more fragile infrastructure, such as gas lines and electrical equipment, whereas less wealthy countries may have older, less well maintained equipment and more open flames. Warm climates may use fewer heating fires than cold climates.

We therefore estimate the risk of ignition in all communities from the same two concepts, the amount of shaking and the resulting damage to infrastructure. Strong shaking, even in the absence of structural damage, has the potential to knock over non-structural elements that could cause fires. Heavy infrastructure damage can also spark fires and in some communities can occur without strong shaking. To represent the level of shaking that a community experiences, we take the average PGA experienced in the city, considering the shaking on firm ground and soft soil. We use the percent of population killed by building damage as a proxy for infrastructure damage.

### Likelihood of Fire Spread

For a fire to grow into a conflagration, conditions must be ripe for the fire to spread. Many conditions influence this spread, but we limit our analysis to three of the key characteristics: building types, building density and wind speed.

The five factors related to ignition and spread are scaled to remove their units and make it possible to combine them. We define a maximum and minimum likely value for each factor (see Table 7) and scale the data for each city between these two values. Those factors that must be non-zero for fire to occur are linearly scaled between zero and four (PGA, flammable buildings, and population density). The remaining factors are linearly scaled between one and five (amount of damage, wind speed).

**Table 7: Assumed Maximum and Minimum Values for Fire Risk Variables**

| Mechanism | Definition | Minimum Possible | Maximum Possible | Scaled Range |
|---|---|---|---|---|
| Ignition | PGA factor | 0%g | 1.05%g | 0 - 4 |
| Ignition | % of population killed by buildings | 0% | 20% | 1 - 5 |
| Spread | % of buildings which are highly flammable | 0% | 100% | 0 - 4 |
| Spread | Population density in persons per square km | 0 pop/km² | 40,000 pop/km² | 0 - 4 |
| Spread | Average annual wind speed in km per hour | 0 km/hr | 40 km/hr | 1 - 5 |

**GESIVILLE: Step 12**

| Factor | Value | Scaled Value |
|---|---|---|
| Average PGA | 0.36%g | 1.37 |
| % killed by bldgs | 0.06% | 1.01 |
| % flammable bldgs | 70% | 2.80 |
| Pop density | 10,000 ppl/sq km | 1.00 |
| Wind speed | 10km/hr | 2.00 |

## Step 13: Measure fire suppression capability

Fire-fighting activities can make a big difference in how far a fire spreads and in the resulting damage. We look at three aspects of fire fighting: the availability of water, the institutional capacity, and the ease of city access. In addition, we look at the general city emergency response preparedness to see whether it will help or hinder the fire fighting efforts.

For sources of water, each city is given a rating of zero to four, with four representing a city with no likely post-earthquake sources of water and zero representing a city likely to have adequate sources of water after a quake. The scoring scheme is presented below:

- The city has no reliable sources of water to fight fires, even before an earthquake strikes (score=4)
- The city has one adequate supply of water to fight fires in non-earthquake times, but this system has not been designed to withstand earthquake shaking - OR - The city has more than one supply of water to fight fires in non-earthquake times, but these systems do not serve the entire city area and have not been designed to withstand earthquake shaking (score=3)
- The city has more than one source of water to fight fires which serve the entire city area adequately, but these systems have not been designed to withstand earthquake shaking (score=2)
- The city has one source of water that serves the majority of the city area that has been designed to withstand earthquake shaking, in addition to other sources of water (score=1)
- The city has more than one source of water to fight fires that has been designed to withstand earthquake shaking, covering the entire city area (score=0)

For institutional capacity (which refers to fire fighters, fire stations, and fire fighting equipment) each city is given a rating from zero to seven, with seven representing a community with almost no capacity to fight fires after an earthquake and zero representing a city with significant capacity to fight post-earthquake fires. The scoring scheme is presented below:

- Are fire stations constructed to resist earthquake shaking? ("yes, always"=0, "yes, but inconsistently"=1, "no"=2)
- Are fire stations well distributed throughout the city area? ("yes"=0, "no"=1)
- Are there more than 2 fire engines and tanker trucks per 100,000 people? ("yes"=0, "no"=1)
- Are there more than 10 fire fighters per 100,000 people? ("yes"=0, "no"=1)
- Are fire fighters adequately trained in fighting fires throughout their career? ("yes"=0, "no"=1)
- Are fire fighters trained to respond specifically after earthquakes? ("yes"=0, "no"=1)

The responses to each question are summed.

Ease of city access is measured as a percentage of city area that is inaccessible to fire engines. This is assessed for a city prior to an earthquake, that is, without considering street blockages that may occur from building damage.

General emergency preparedness can improve or impede fire suppression. Streets must be cleared, traffic must be controlled and activities need to be thoughtfully prioritized for effective fire suppression. The general emergency response rating, from 0 to 16, as used for search and rescue is also included in the analysis of fire risk.

Finally, we scale the four fire-fighting measures between zero and four, as shown in Table 8.

**Table 8: Assumed Maximum and Minimum Values for Fire Suppression Variables**

| Mechanism | Definition | Minimum Possible | Maximum Possible | Scaled Range |
|---|---|---|---|---|
| Fighting | Water availability score | 0 | 4 | 0 - 4 |
| Fighting | Institutional capacity score | 0 | 7 | 0 - 4 |
| Fighting | % of city area inaccessible to fire engines | 0% | 80% | 0 - 4 |
| Fighting | General emergency preparedness score | 0 | 16 | 0 - 4 |

**GESIVILLE: Step 13**

| Factor | Value | Scaled Value |
|---|---|---|
| Water avail. | 2 | 2.00 |
| Fighting capac. | 4 | 2.29 |
| % area inaccess. | 5% | 0.25 |
| Gen. emer. resp. | 12 | 3.00 |

## Step 14: Convert fire data into deaths and injuries due to fire

Finally, we combine the information on ignition, spread and suppression and relate it to the percent of the population likely to die in earthquake-induced fires. To do this, the scaled values for ignition and spread are multiplied. The fire-fighting factors are then summed, with a possible maximum score of sixteen. For a city with a combined fire suppression score of sixteen, we assume fire suppression efforts have no impact on spread. Cities with a fire suppression score of zero are assumed to reduce their fire spread by half. Scores between zero and sixteen are linearly scaled between these values.

Finally, we look to past earthquakes to link our nine factors to life loss. We calibrate the model by estimating the conditions during the Kobe earthquake of 1995 and assuming that 0.04% of the population in Kobe was killed by fire. We further assume that a fire rating of zero corresponds to no one being killed and that the percentage of the population killed scales linearly with the fire rating.

**GESIVILLE: Step 14**

Spread reduction factor : 0.5 + (2.00+2.29+0.25+3.00)/32 = 0.74
Fire Score: (1.37)(1.01)(2.80)(1.00)(2.00)(0.74) = 5.73
Number of deaths by fire = (5.73)(0.04%)/2.94 = **0.078%**
Number of life-threatening injuries by fire = **0.078%**

**Sources:**


1. Coburn *et al.* "Factors Determining Human Casualty Levels in Earthquakes: Mortality Prediction in Building Collapse." Proceedings of the Tenth World Conference on Earthquake Engineering. 1992, pp. 5989 – 5994.
2. EQE International, http://www.eqe.com/publications/kobe/escience.htm
3. Japan Statistical Association. Historical Statistics of Japan. 1987.
4. Japan Statistical Yearbook. 1997.
5. National Institute of Building Sciences (NIBS), HAZUS Technical Manual. Federal Emergency Management Agency, 1997. Volume III, pp. 10-1 to 10-20.
6. Miyazake, Hiroshi and Masakazu Moriyama. "Area Characteristics of Urban Structure and the Seismic Fires at Kobe Earthquake." Confronting Urban Earthquakes. Ed. Kenzo Toki. March 2000, pp. 654 to 657.
7. Murakami, Hitomi *et al.* "Study on Search and Rescue Operations in the 1995 Hanshin-Awaji Earthquake – Analysis of Labor Work in Relation with Building Types." Proceedings of the 12th World Conference on Earthquake Engineering. Auckland, New Zealand, 2000, paper No. 0272.
8. Nagano, Yuzo. "Fire Damages." Comprehensive Study of the Great Hanshin Earthquake. UNCRD, Nagoya, Japan. 1995, pp. 107 - 126.
9. Taniguchi, Hitoshi. "Background of the Hanshin Area." Comprehensive Study of the Great Hanshin Earthquake. UNCRD, Nagoya, Japan. 1995, pp. 1 – 5.
10. Tokyo Metropolitan Government. Tokyo and Earthquakes. 1995.


## Step 15: *Measure emergency medical capability*

Our first step in evaluating emergency medical care is to estimate the demand likely to be placed on it. This comes from three sources: injuries from buildings, injuries from landslides, and injuries from fire.

By summing these variables, we estimate the number of people who could potentially be saved by medical care.

Next we must estimate how effective the medical system may be at saving them. Each city's medical emergency preparedness is rated from zero to sixteen, as shown below:

- Are there more than 100 available hospital beds per 100,000 people (available means not occupied)? ("yes"=0, "no"=1)
- Are hospitals and other emergency care centers well distributed throughout the city or are they clustered in one part of the city? ("well distributed"=0, "clustered"=1)
- Is there coordination between all hospitals in the city to manage large numbers of patients during an emergency? ("yes"=0, "yes, but needs improvement"=1, "no"=2)
- Is there an earthquake resistant communications system that hospitals can use? ("yes"=0, "no"=1)
- Are hospital staff trained in emergency procedures such as triage, management, etc? ("yes"=0, "some are trained"=1, "no"=2)

- Is there a system to provide medical care to wounded before they reach hospitals? ("yes"=0, "no"=1)
- Is there an ambulance system with at least 5 ambulances per 100,000 people? ("yes"=0, "no"=1)
- Are hospital structures built to withstand earthquakes? ("yes, always"=0, "yes, but inconsistently"=1, "no"=2)
- Have hospitals taken into account non-structural safety measures? ("yes"=0, "no"=1)
- Do hospitals have an earthquake resistant, independent power source? ("yes"=0, "no"=1)
- Do hospitals regularly practice mass casualty and evacuation drills? ("yes"=0, "yes, but less than annually or not all hospitals"=1, "no"=2)
- Do hospitals have adequate amounts of emergency supplies? ("yes"=0, "no"=1)

The responses to each question are summed.

**GESIVILLE: Step 15**

Total injuries requiring care: 0.06% + 0.075% + 0.078% = 0.213%
Medical preparedness rating: 6

## Step 16: Convert medical capability into effect of medical care

The medical preparedness rating is added to the city's for general emergency preparedness rating, as determined in step 10. The sum will range from zero to 32. We assume that a value of zero means that all injured people survive, but not to exceed 1% of the population (we assume that no city, no matter how well prepared, can provide medical care to more than 1% of its population). A value of 32 means that none of the injured people survive. A value between zero and 32 is linearly scaled between no lives saved and the lesser of the total number of injuries and 1% of the total population.

**GESIVILLE: Step 16**

General emergency response preparedness rating: 12
Percentage of those needing care who die: (6+12)/32 = 56%
Percent of population saved by medical care = **(44%)(0.213%) = 0.094%**

## Step 17: Combine results

Finally we sum the deaths and injuries from all causes.

**GESIVILLE: Step 17**

| | |
|---|---|
| Building fatality potential: 0.06% + 0.06% | 0.12 % |
| Landslide fatality potential: 0.075% + 0.075% | 0.15 % |
| Search and rescue life saving potential | 0.008 % |
| Fire fatality potential: 0.078% + 0.078% | 0.156 % |
| Medical care life saving potential | 0.094 % |
| **Per capita earthquake lethality potential** | 0.324 % |

**Total earthquake lethality potential = (0.324%)(2,000,000) = 6,480**

## Step 18: Calculate the Emergency Response contribution to city risk

So far, the city's ability to respond quickly and effectively after a disaster has contributed to the calculation of Earthquake Fatality Potential, but has not been calculated independently. General emergency response is a large factor in both Search and Rescue life saving potential and Medical

Care life saving potential, but is not a life saving potential itself since having an emergency plan or redundant communications alone is not enough to save lives.

However looking at the contributors to the risk of a city, it is clear than an organized, informed emergency management team could reduce the overall risk of a city. In this step, we will calculate the contribution of emergency response to the city's risk to 'assign' a portion of the fatalities to the city's general ability to prepare for and manage earthquake disasters and present it as a percentage of the city's risk.

The fatalities attributable to inadequate emergency response have been embedded in fire suppression and medical care efficiency. Here we will first calculate the fatalities due to inadequate fire suppression that can be attributed to emergency response insufficiency, and second we will calculate the fatalities due to inadequate medical care that are attributable to emergency response insufficiency.

The percentage of fire fatalities that can be assigned to general emergency response capacity problems is calculated by multiplying the contribution of general emergency preparedness to fire suppression capacity with the fatalities caused by earthquake-induced fires. This value is divided by the earthquake lethality potential to present it as a percentage of the city's total risk.

The portion of medical care efficiency that is contributed by emergency response is calculated by multiplying the contribution of medical care emergency preparedness by the percentage of the population who could possibly be saved by medical care. This represents the number of people that the medical system is capable of saving assuming the city has a perfect emergency response capacity. The percentage of the population who are saved is subtracted out, and the percentage of fatalities that remains are attributed to general emergency response. The value is then divided by the earthquake lethality potential and presented as a percentage of the city's total risk.

The values calculated from fire suppression and medical care are added together to produce the fatalities attributed to emergency response.

**GESIVILLE: Step 18**

*Scaled value of general emergency response's contribution to fire spread reduction: 3 [step 13]*
*Fire spread reduction factor: 0.74 [step 14]*
General emergency response contribution to fires: (3/32)/0.74 = 13%
Fatalities from general emergency response problem in fires: 13%*0.078% = 0.010%
Per capita earthquake lethality potential = 0.324%
**General emergency response contribution to fire fatalities** = 0.010%/0.324% = **3.1%**

*Medical preparedness rating: 6 [step 15]*
Contribution of medical care preparedness: 1-6/32 = 0.81
*Total injuries requiring medical care: 0.213% [step 15]*
*Percentage of population saved by medical care: 0.09% [step 16]*
Fatalities caused by general emergency response's contribution to medical care = 0.213%*0.81- 0.09% = 0.080%
**General emergency response contribution to medical care** = 0.080%/0.324% = **24.7%**

**Contribution of general emergency response to city risk** = 3.1%+24.7% = **28%**

## Step 19: Calculate the Medical Care contribution to city risk

Once the contribution of emergency response preparedness to the city's risk has been calculated, the respective contributions of the other five sources of risk to the total risk must also be calculated, as they are interconnected, and effectively modify each other.

To calculate the percentage of risk that is attributable to Medical Care insufficiency, the percentage of the population that could possibly be saved by medical care is multiplied by the contribution of emergency response preparedness to medical efficiency. This represents the percentage of the population that are aided by city emergency efforts, but do not survive because of insufficient medical care. The percentage of the population who are saved is subtracted from the total, and the remainders are attributed to insufficient medical care. The number is divided by the total fatality percentage to get the contribution of Medical Care to the city's source of risk.

**GESIVILLE: Step 19**

*General Emergency Response preparedness rating: 12 (step 16)*
Contribution of general emergency resonse preparedness: 1-12/32 = 0.62
*Total injuries requiring medical care: 0.213% (step 15)*
*Percentage of population saved by medical care: 0.09% (step16)*
Fatalities from medical care problem = 0.213%*0.62 - 0.09% = 0.040%
**Contribution of medical care to city risk** = 0.040%/0.324% = **12%**

## Step 20: Calculate the Search and Rescue contribution to city risk

The contribution of search and rescue to the city's risk is calculated by estimating the percentage of the population that could possibly be saved if search and rescue worked at maximum efficiency, which is represented as the smaller of one half of all fatalities or 60% of the firefighters (this number represents a high search and rescue capacity). The percentage of the population that is saved by organized search and rescue is then subtracted out to represent the percentage of the total number of fatalities that could have been saved by search and rescue but were not. The final number is divided by the total fatality percentage to get the overall contribution to the city's risk.

**GESIVILLE: Step 20**

Half of total fatalities from building and landslides: (0.06%+0.075%)(2,000,000)/2 = 1,353
60% of the number of firefighters: 60%*500 = **300** (smaller number)

Estimate maximum percentage that could be saved by search and rescue: 300/2,000,000 = 0.015%
*Percent of population rescued = 0.008% (step 11)*
Fatalities from search and rescue problem = 0.015%- 0.008% = 0.007%
**Contribution of search and rescue to city risk** = 0.007%/0.324% = **2%**

## Step 21: Calculate the Building Collapse contribution to city risk

The portion of the city's risk that is attributed to building collapse is equal to the percentage of population killed by building collapse once search and rescue is taken into account. Search and rescue reduces the contribution of building collapse to the city's risk in two ways. First, the number is reduced by the percentage of the total population saved from building collapse by organized search and rescue. Second, the number is further reduced because a portion of the fatalities are attributed to search and rescue insufficiency, and subtracted from the building collapse total. The total is then divided by the total fatality potential to obtain the contribution building collapse will make to the city's sources of risk.

**GESIVILLE: Step 21**

*Percent of population rescued = 0.008% (step 11)*
*Fatalities from search and rescue problem = 0.007% (step 20)*
*Population injured by buildings = 0.06% (step 5)*
*Population injured by landslides = 0.075% (step 9)*
Percent of population saved from building by search and rescue = 0.06%/(0.06%+0.075%)*0.008% = 0.004%
Percent of population killed in buildings attributed to search and rescue inefficiencies
= 0.06%/(0.06%+0.075%)*0.007% = 0.003%
Fatalities from building = 0.06%-0.004%-0.003% = 0.05%
**Contribution of building to city risk** = 0.05%/0.324% = **16%**

## Step 22: Calculate the Landslide contribution to city risk

Calculating the contribution of earthquake-induced landslides to the city's risk is identical to calculating the contribution of building collapse. It is equal to the percentage of population killed by landslides once you account for search and rescue and is presented as a percentage of a city's total sources of risk.

**GESIVILLE: Step 22**

*Percent of population rescued = 0.008% [step 11]*
*Fatalities from search and rescue problem = 0.007% [step 20]*
*Population injured by buildings = 0.06% [step 5]*
*Population injured by landslides = 0.075% [step 9]*
Percent of population saved from landslides by search and rescue = 0.075%/(0.06%+0.075%)*0.008% = 0.004%
Percent of population killed in landslides attributed to search and rescue inefficiencies
= 0.075%/(0.06%+0.075%)*0.007% = 0.004%
Fatalities from landslides = 0.075%-0.004%-0.004% = 0.068%
**Contribution of earthquake-induced landslides to city risk** = 0.068%/0.324% = **21%**

## Step 23: Calculate the Fire contribution to city risk

The contribution to the city's risk from fires comes from insufficiency in fire suppression. The percentage of city risk caused by fires is calculated by summing the contributions from the city's water availability, firefighting capacity and the area of the city that is inaccessible to fire trucks. When these three contributions are scaled and their relative weights with respect to suppression are determined, they are multiplied by the total fatalities caused by fires. This contribution to the city's risk is then presented as a percentage of the total city risk.

**GESIVILLE: Step 23**

*Scaled value for water availability: 2 [step 13]*
*Scaled value for firefighting capacity: 2.29 [step13]*
*Scaled value for percent area inaccessible to fire trucks: 0.25 [step 13]*
*Spread reduction factor: 0.74 [step 14]*
Insufficiency in fire reduction: ((2+2.29)/32 + (0.5+(0.25/32)))/0.74 = 0.867
*Fatalities from fires: 0.078% [step 14]*
**Contribution of fires to city risk** = 0.867*0.078%/0.324% = **21%**

## Step 24: Combine results

Finally we combine all the sources of risk.

**GESIVILLE: Step 24**

| | |
|---|---|
| Emergency response problems | 28% |
| Medical care problems | 12% |
| Search and Response problems | 2% |
| Building collapse | 16% |
| Landslides | 21% |
| Fires | 21% |
| **TOTAL** | **100%** |

## Step 25: Repeat analysis for schools

We repeat steps one through twenty-four for the schools in each city. To do this, we replace the building inventory with an inventory of school buildings and assume an even distribution of schools around the city. The number of children who attend school replaces the total population. All other aspects of the analysis remain the same.

## Step 26: Analyze risk management potential

Not all risk management activities are equally effective in all cities. We make rough estimates of the relative effects of a few different mitigation activities by changing each city's data set to reflect the accomplishment of a risk management goal. Different activities are compared according to their ability to reduce life loss.

## Things Not Included

### Infrastructure (Non-Building) Deaths

Earthquakes can cause deaths not only when buildings collapse but also when non-building infrastructure such as freeway bridges collapse. In recent California earthquakes, total fatalities have been light, and infrastructure deaths have made up a significant percentage of total deaths. However, such non-building deaths seem to become insignificant as casualty totals mount.

### Liquefaction

Liquefaction, a phenomenon in which saturated ground loses strength or stiffness when shaken, has caused immense economic loss in many earthquakes. Buildings located on liquefiable soils can settle or tip when exposed to shaking. Underground infrastructure may "float" to the surface. While expensive, such consequences have not caused many deaths in past earthquakes (Durkin and Thiel, p. 295). Therefore, liquefaction is not included in our method.

### Tsunami

Not all coastal communities with earthquake risk have a significant risk of experiencing locally generated tsunamis. Estimating the expected casualties from tsunamis is difficult because casualties depend on the size of the tsunami, the local topography, the orientation of the coast relative to distant seismogenic areas of the world, the population density, the warning time, etc.

### Hazardous Materials Release

In theory, hazardous materials released during an earthquake could cause many deaths, especially if the material released were poisonous or flammable. To date there have been no major hazardous materials releases associated with earthquakes. This concept is currently excluded from the GHI model because of the difficulty of collecting information.

### Dam Collapse

Some important cities are located downstream from vulnerable dams. The failure of such a dam could cause many deaths. However, including this concept would require collecting reliable information about a single structure, which does not seem possible to us at this time.

**Sources:**

1. Durkin, Michael E. and Charles C. Thiel. "Estimating Casualties in Earthquakes: An Assessment." Proceedings of the Fourth International Conference on Seismic Zonation. Earthquake Engineering Research Institute: Stanford, CA, 1991. Volume III, pp. 293 – 300.

Appendix 3

# Sample Questionnaires

THIS appendix includes two sample Questionnaires — the City Planning and City Emergency Response Questionnaires — that were used to collect some of the data needed for the GHI method. Six other Questionnaires were used that addressed building inventory, school buildings, medical emergency preparedness, hospital emergency preparedness, post-earthquake fire preparedness and seismology, soil and landslides.

## City Planning Questionnaire

Earthquakes are a growing problem around the world. The purpose of this questionnaire is to collect information concerning your city's earthquake risk. This is part of a worldwide initiative being conducted by your city, the United Nations Centre for Regional Development and GeoHazards International.

Please fill out the following questionnaire to the best of your abilities, using any references that you need. If you do not know the answer to any of the questions, please write your best estimate and note that it is an estimate. Please list all sources of information for your responses. You may wish to attach additional sheets of paper to the questionnaire.

Your responses will be used to help determine the level of earthquake risk present in your city.

1. The attached map shows the greater metropolitan area of your city. What is the population of this greater metropolitan area? Please make sure that you consider the entire area shown on the map.
2. What is the population density for each (neighborhood, ward, district, zip code) within the greater metropolitan area of the city? You may wish to attach a separate sheet with this information. If population density information is not available at this level of detail for the entire greater metropolitan area, please note this and provide the best information available.
3. What is the annual population growth rate in the city today?

4. What do you estimate will be the population growth rate in 15 years?
5. What percent of your city's population reside in informal settlements in which city planning regulations are not observed?
6. Please list any neighborhoods in your city, which have extremely narrow roads (less than 4 meters wide)? Estimate the percentage of the city area that has roads this narrow.
7. Please list the neighborhoods in your city that experience the most frequent fires.
8. Are there any city regulations requiring new development to be built in a fire resistant manner, such as requiring fire lanes or requiring fire resistant building materials to be used? If so, how well are these laws enforced (consider both formal and informal settlements)?
9. Please list the neighborhoods in your city, if any, which have experienced landslides?
10. Please list the neighborhoods in your city, if any, which have experienced subsidence (sinking of the ground)?
11. Please list the neighborhoods in your city, if any, which have experienced flooding.
12. Are there any city regulations which prohibit or control construction on unstable land (land prone to landslides, subsidence, flooding or similar problems)? If so, how well are these regulations enforced (consider both formal and informal settlements)?
13. Which areas within the outline on the attached map are experiencing a growth in population? In other words, which areas of the city are experiencing the most new construction and an increase in population density?
14. Which areas within the outline on the attached map are experiencing a decrease in population?
15. Has your city included issues of earthquake safety in your city planning? If so, please describe how below. If necessary, attach another sheet describing these programs. In particular, if you think your city has any lessons to share with other cities, please describe them here.

Thank you very much for completing this questionnaire and helping us work toward global earthquake safety.

## Emergency Response Questionnaire

Please fill out the following questionnaire to the best of your abilities, using any references that you need. If you do not know the answer to any of the questions, please write your best estimate and note that it is an estimate. Please list all sources of information for your responses. You may wish to attach additional sheets of paper to the questionnaire.

Your responses will be used to help determine the level of earthquake risk present in your city.

1. Which organization has lead responsibility for coordinating the emergency response in your city after an earthquake strikes?
2. Which organization has lead responsibility for coordinating and planning emergency preparedness and mitigation in your city?
3. Is there a detailed emergency response plan for the city in written form? An emergency response plan is a document which details who is responsible for carrying out specific actions; identifies personnel, equipment, facilities, supplies and other resources available for use during disaster; and outlines how all actions will be coordinated. If possible, please attach a copy of the emergency plan to this questionnaire.
4. Does this plan specifically address earthquakes?
5. Which organization or organizations are responsible for writing this plan? What is the process used to write this plan?

6. Do all of the agencies that would need to respond during an emergency (including agencies such as utilities and public works) know about the emergency plan? What is the process used to educate them about their role in the plan?
7. When was the plan most recently revised or updated? What was the process used to do this?
8. Are responsibilities during an emergency clear and well defined? Does each organization know exactly what tasks they are responsible for? Consider organizations as varied as the police, army, municipality, hospitals, utilities, public works, etc.
9. Is it clear how city, state and national level organizations relate to each other during the emergency response? Which level of government is responsible for directing the city's emergency response?
10. Is it clear how different agencies within your city will communicate with each other during a disaster? Is there a disaster resistant communications system? Are there protocols for agencies to keep each other informed about the status of the emergency?
11. How will emergency response organizations communicate with each other after an earthquake if phone lines are not functioning?
12. Is there a central command room where emergency response activities are coordinated and information about the emergency is centralized and managed? If so, is this located in an earthquake-resistant building? Does this command room have earthquake-resistant power and communications systems? Is there a staff trained in operating this command room?
13. Is there a standardized process to assess the level of damage caused by the earthquake? For example, will organized teams of engineers examine the safety of buildings in the city immediately after a quake? Are engineers trained to do this in advance? Are there standardized forms and reporting systems?
14. Are there trained search and rescue teams in the city?
15. Are there provisions for communicating with the public during a disaster?
16. Are there any community-level emergency training or preparedness programs in your city? If so, please briefly describe them.
17. Are there any arrangements for nearby cities or states to help your city during a disaster? Are there any arrangements for international assistance?
18. Are there any plans for mass care and sheltering of victims and survivors after an earthquake? For example, has any organization planned for housing shelters, food, sanitation and supplies for people made homeless by an earthquake?
19. Does the city conduct emergency drills for natural disasters that involve all key organizations involved in emergency response? If so, when was the most recent drill?
20. Do any organizations within the city conduct emergency drills for natural disasters independently, such as hospitals, police, fire department? If so, when were the most recent drills?
21. Has there been a major disaster that affected the city in the last 10 years when emergency response was required? If so, what type of disaster?

    *If yes, answer question 22. If no, go to question 23.*

22. When the disaster occurred, was there an emergency plan for the city? If so, how successful was the emergency response using that plan? Has the plan been revised since that time?
23. Are there any aspects of your city's emergency planning that you think would be interesting to share with other cities? If so, please describe them below.

Thank you very much for completing this questionnaire and helping us work toward global earthquake safety.

Appendix 4

# Risk Summary for Antofagasta, Chile

MANY factors affect the risk of an earthquake catastrophe in a city, from the likelihood of experiencing an earthquake to the quality of a city's buildings to the readiness of emergency preparedness teams in the city. For the Global Earthquake Safety Initiative (GESI), specialists collected information about all of these factors and more for Antofagasta to get a complete picture of the city's earthquake risk. In this report, we present GESI's preliminary findings, divided into four parts. In the first part we examine how the risk of Antofagasta compares to the risk in other cities in the Americas. In the second part, we take a detailed look at the factors that are responsible for the earthquake risk in Antofagasta. Third, we examine how Antofagasta could most effectively reduce its earthquake risk in the future. Last, we focus on the risk to the city's schools.

All of the results presented in this report are preliminary. We look forward to your comments about these findings.

## Comparison of Earthquake Risk to Other Cities

We look at the risk of Antofagasta in five different ways and rate each aspect of risk as Very Low, Low, Moderate, High, Very High or Extremely High. First we present the ratings for Antofagasta. Then we present how other cities were rated. The rating scheme was developed by considering the range of risk in cities around the world. It is a subjective scale, and to help you understand its implications we define how Earthquake Lethality Potential relates to expected loss of life:

**Table: Earthquake Lethality to Expected Life Loss**

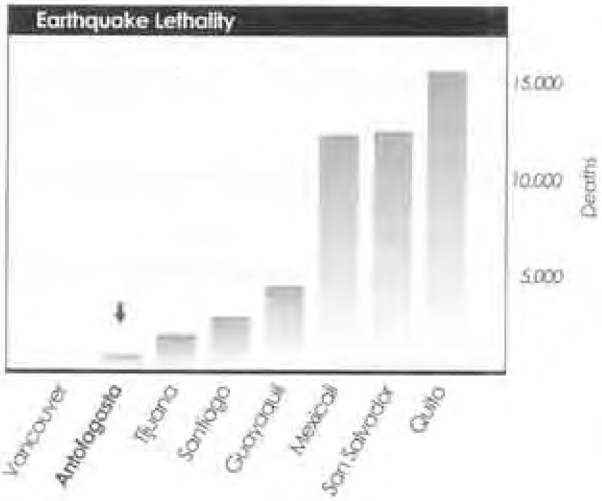
| | |
|---|---|
| Very Low | There is a 1 in 10 chance that **fewer than one hundred casualties** will occur in the city due to earthquakes during the next 50 years. |
| Low | There is a 1 in 10 chance that **hundreds of casualties** will occur in the city due to earthquakes during the next 50 years. |
| Moderate | There is a 1 in 10 chance that **hundreds to low thousands of casualties** will occur in the city due to earthquakes during the next 50 years. |
| High | There is a 1 in 10 chance that **thousands of casualties** will occur in the city due to earthquakes during the next 50 years. |
| Very High | There is a 1 in 10 chance that **thousands to tens of thousands of casualties** will occur in the city due to earthquakes during the next 50 years. |
| Extremely High | There is a 1 in 10 chance that **tens of thousands or more casualties** will occur in the city due to earthquakes during the next 50 years. |

## Antofagasta Risk Ratings

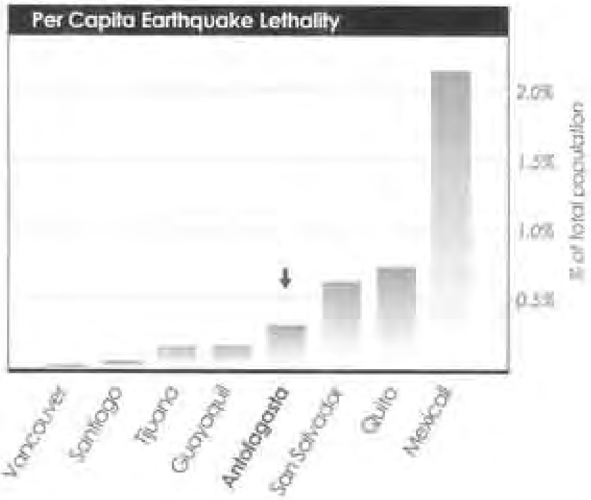
**Table: Antofagasta Risk Ratings**

| | |
|---|---|
| **Earthquake Lethality**<br>The likelihood of casualties from earthquakes in the city. (Small cities should expect a lower rating than large cities for this category.) | Moderate |
| **Per Capita Risk Earthquake Lethality**<br>The likelihood of an individual being killed in an earthquake in the city. (This category treats small cities and large cities the same.) | High |
| **Hazard**<br>Likelihood of experiencing strong earthquake shaking. (This includes the effects of local soil conditions.) | Very High |
| **Lethality of Buildings**<br>Potential for buildings to kill people if strong earthquake shaking is experienced. (This does not consider the likeliness of earthquakes shaking.) | High |
| **Response Preparedness**<br>Potential that emergency response will be ineffective at saving lives. (This combines evaluation of fire fighting preparedness, medical care preparedness and general emergency response preparedness.) | Moderate |

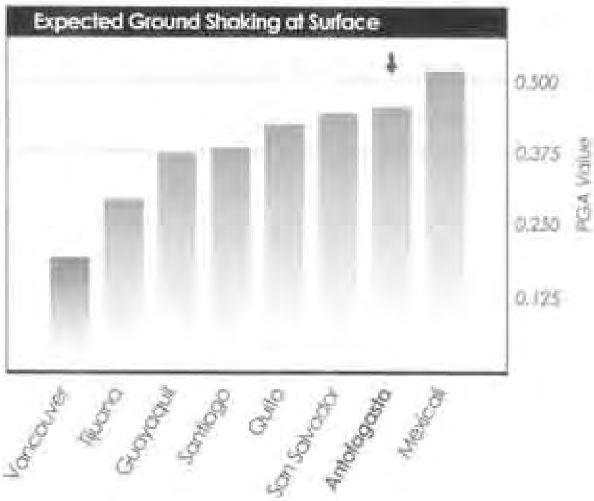
This chart shows how the seven other cities in the Americas that participated in GESI compare to Antofagasta in Earthquake Lethality Potential. This measure can be regarded as a rough estimate of the number of lives that would be lost if all parts of the city, as it exists today, experiences shaking at the level that has a 10% chance of being equaled or exceeded in 50 years.



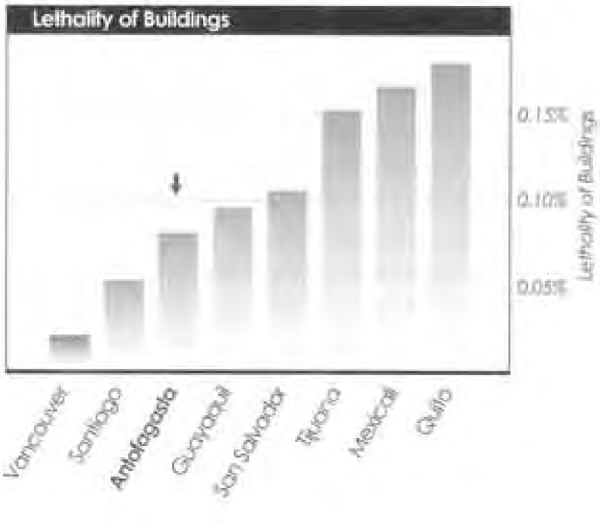
This chart shows how the seven other cities in the Americas that participated in GESI compare to Antofagasta in Per Capita Earthquake Lethality Potential. This presents the same information as above, but removes that influence of population by expressing the results as a percentage of the total population.



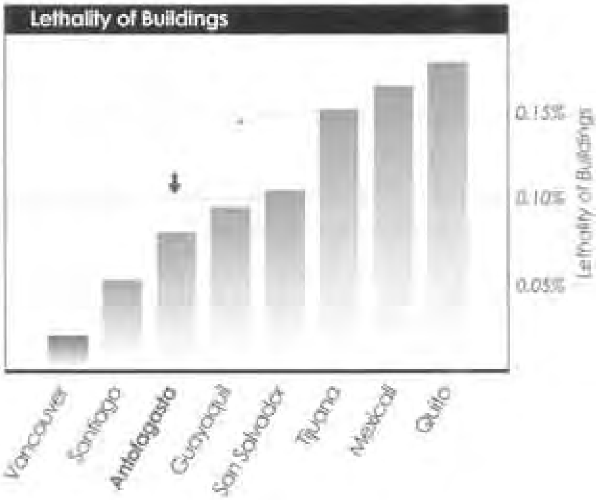

This chart shows how the seven other cities in the Americas that participated in GESI compare to Antofagasta in Hazard. This method defines Hazard as the shaking experienced by the entire city, which combines Peak Ground Acceleration and the effect of soft soil.




This chart shows how the seven other cities in the Americas that participated in GESI compare to Antofagasta in Lethality of Buildings. The method defines Building Lethality as the percentage of population killed by building collapse using the building stock as it exists today in each city. This comparison is conducted by assuming that all cities have the same peak ground acceleration and percentage of soft soil.



This chart shows how the seven other cities in the Americas that participated in GESI compare to Antofagasta in Response Preparedness. Response Preparedness is a reflection of the preparedness level of the combined emergency resources for the city, and is calculated by adding the Emergency Response Capacity and Medical Emergency Response scores.




## Components of Earthquake Risk of City

This chart shows the factors that make up Antofagasta's risk as measured by the GESI project.


## Potential to Reduce Earthquake Lethality Potential

This chart shows some of the activities that could effectively reduce Antofagasta's earthquake risk. This analysis was made using certain assumptions about Antofagasta's growth patterns and construction practices. In this example, each option is assessed independently, assuming that all other factors remain unchanged. The results indicate the possible reduction in Earthquake Lethality Potential that could be achieved if the city perfected their scores on Emergency Response and Medical Care Preparedness, maximized their Search and Rescue Capacity, eliminated the most vulnerable 5% of the existing building stock, and improved the design and construction practices of new development using local materials and building types.

## Close-up Look at Risk of School System

The techniques used to analyze the risk of the entire city can also be used to analyze a portion of the city or a particular system within the city. To demonstrate this, we include an analysis of the risk of the school system of Antofagasta to earthquakes. This close-up look at schools parallels the risk summary presented for the entire city by first showing how the safety of the school system of Antofagasta compares to school systems of other cities, then identifying the particular causes of risk to the school system and, last, looking at ways to reduce the risk to the city's schools.

### Comparison of Earthquake Risk to School System to Other Cities

We look at the risk of Antofagasta's schools in three different ways and rate each aspect of risk as Very Low, Low, Moderate, High, Very High or Extremely High. First we present the ratings for Antofagasta's schools. Then we present how the schools of Antofagasta compare to those of other cities in terms of earthquake risk. The rating scheme was developed by considering the range of risk in cities around the world. It is a subjective scale, and to help you understand its implications we define how Earthquake Lethality Potential relates to expected loss of life:

**Table: Earthquake Lethality to Expected Life Loss**

| | |
|---|---|
| Very Low | There is a 1 in 10 chance that **fewer than fifty casualties** of school children will occur in the city due to earthquakes during the next 50 years. |
| Low | There is a 1 in 10 chance that **dozens of casualties** of school children will occur in the city due to earthquakes during the next 50 years. |
| Moderate | There is a 1 in 10 chance that **hundreds of casualties** of school children will occur in the city due to earthquakes during the next 50 years. |
| High | There is a 1 in 10 chance that **hundreds of thousands of casualties** of school children will occur in the city due to earthquakes during the next 50 years. |
| Very High | There is a 1 in 10 chance that **thousands of casualties** of school children will occur in the city due to earthquakes during the next 50 years. |
| Extremely High | There is a 1 in 10 chance that **tens of thousands of casualties** of school children will occur in the city due to earthquakes during the next 50 years. |

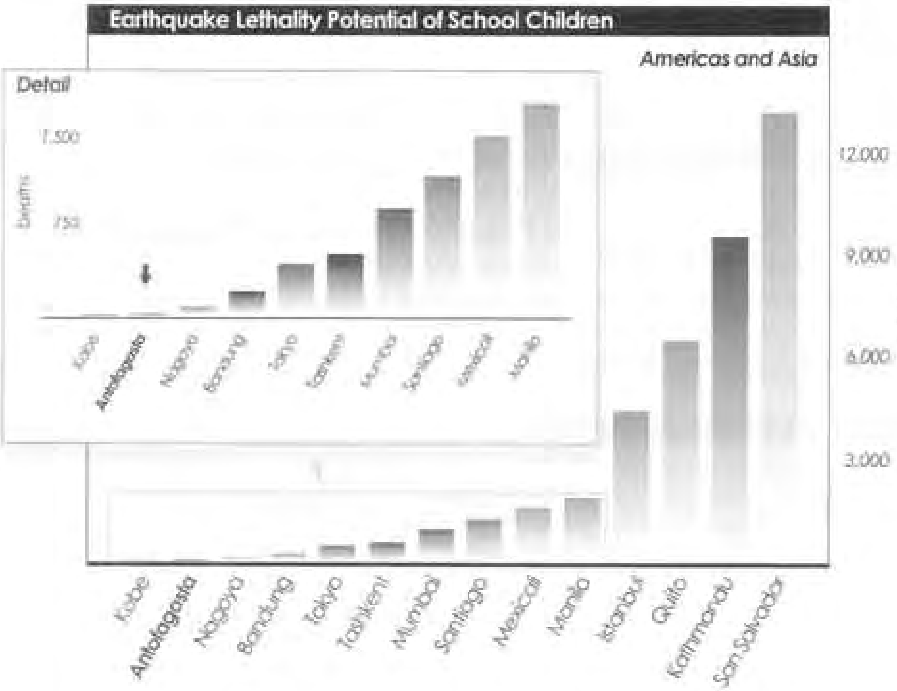
### Antofagasta School Risk Ratings

**Table: Antofagasta School Risk Ratings**

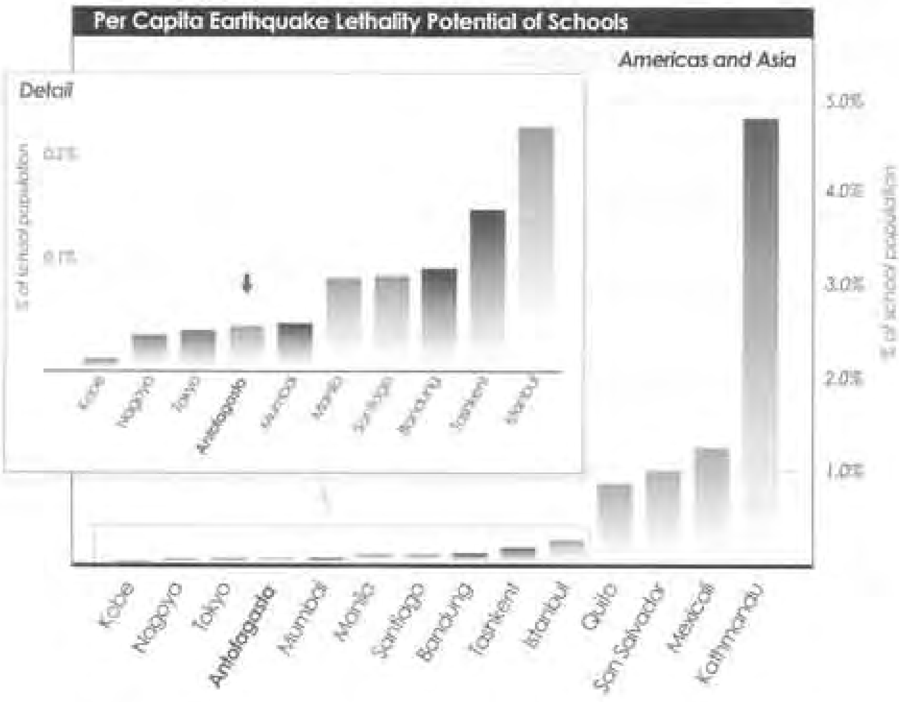
| | |
|---|---|
| **Earthquake Lethality of School Children**<br>The likelihood of casualties in school in the city. (Small cities should expect a lower rating than large cities for this category.) | Low |
| **Per Capita Risk Earthquake Lethality of School Casualties**<br>The likelihood of an individual school child to be killed in an earthquake in the city. (This category treats small cities and large cities the same.) | Moderate |
| **Lethality of School Buildings**<br>Potential for buildings to kill people if strong earthquake shaking is experienced. (This does not consider the likeliness of earthquakes shaking.) | Moderate |

The charts presented for school children have the same interpretation as the results presented for the city as a whole.

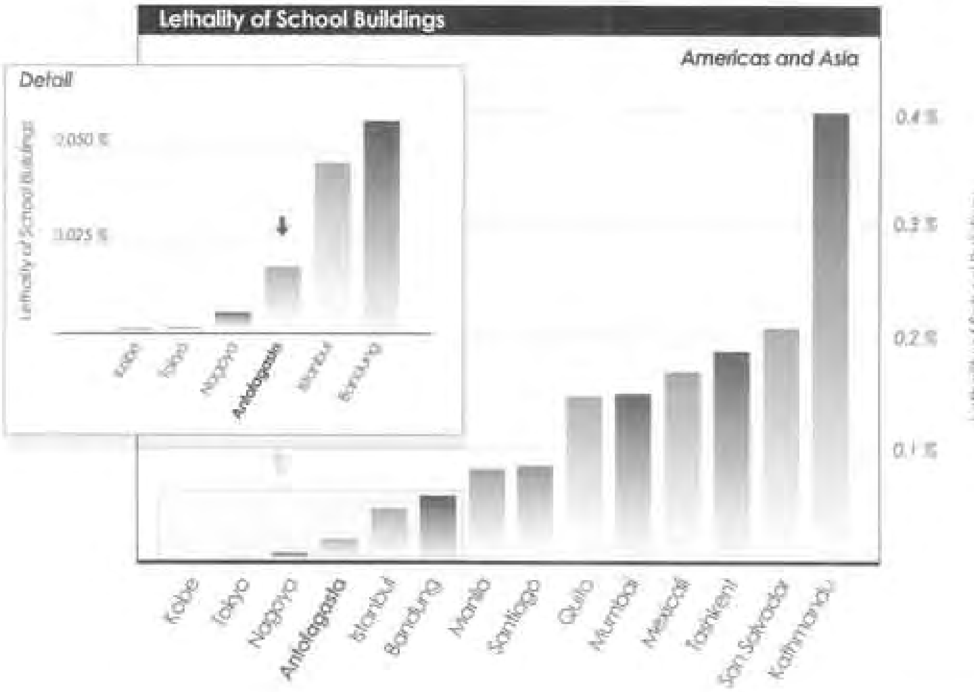
The chart below shows how the thirteen other cities that looked at their school systems compare to Antofagasta in Earthquake Lethality Potential of School Children.




The chart below shows how the thirteen other cities that looked at their school systems compare to Antofagasta in Per Capita Earthquake Lethality Potential of School Casualties.



The chart below shows how the thirteen other cities that looked at their school systems compare to Antofagasta in Lethality of School Buildings.

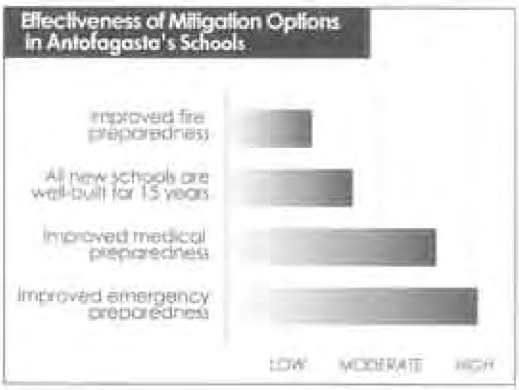


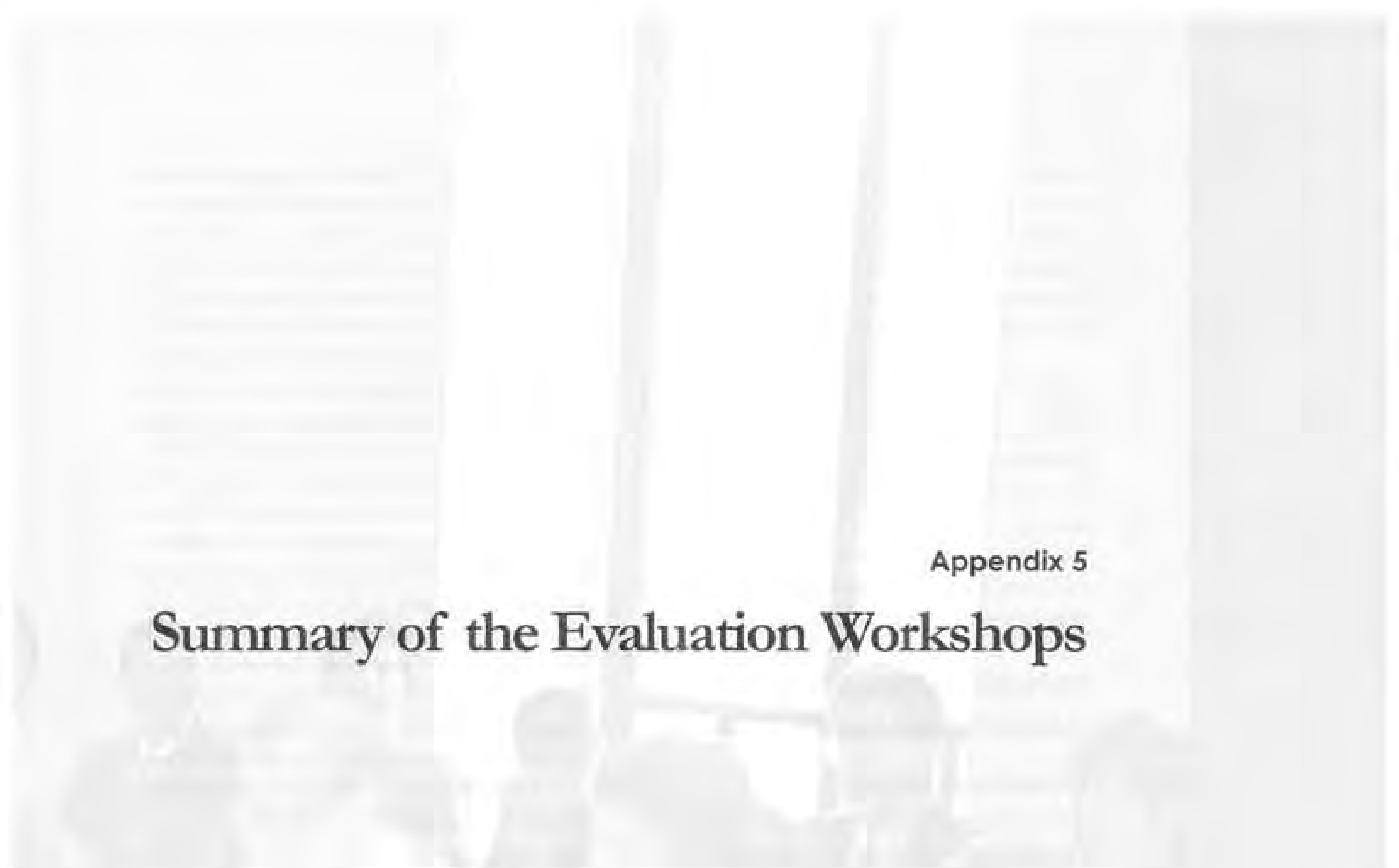

## Components of School Earthquake Risk

This chart shows the factors that make up the risk to Antofagasta's school system as measured by the GESI project.


## Potential to Reduce School Earthquake Risk

This chart shows some of the activities that could effectively reduce Antofagasta's earthquake risk to school children.





Appendix 5

# Summary of the Evaluation Workshops

TWO workshops – one in Kobe, Japan on January 29-31, 2001 for the GESI participants from Asia and one in Quito, Ecuador on March 5-7, 2001, for the GESI participants from Latin America – were held to evaluate the GESI Pilot Project and to solicit recommendations concerning future actions.

The programs of both workshops were similar. In each workshop, the participants were divided into the following three working groups based on their expertise: representatives from cities that participated in GESI, representatives from international organizations, and technical experts. The three groups evaluated the project in four discussion sessions over the course of two days. Each group had a Reporter and a Leader.

The first session, "Results," examined the usefulness of the results, ways of improving their usefulness, and the focus on school systems. Participants commented on the potential of the project to motivate action, and discussed whether GESI should continue, and if so, whether in its present form, or some modified form. The technical experts also evaluated the method and suggested improvements.

In the second session, "Process," the three groups evaluated how the data were collected and the results disseminated. The discussion about data collection centered on the relative merits of official and unofficial data, sensitivities about the data, and possible improvements to the process. There were discussions about who should release the results and when, and how the presentation of results could be improved. The group of technical experts also proposed ways of validating both the method and the data.

In the third session, "Future," all three groups made suggestions for motivating action and promoting risk mitigation awareness. They were asked whether GESI needed to include more cities. They also discussed the level of detail of the results, the proper audience to motivate action, and the expansion of the project to hospitals and other health systems.

In the fourth session, "Conclusions," a plenary session, the Reporters and Leaders of each of the three preceding sessions summarized the preceding sessions to all the workshop participants. The focus of this plenary session was to identify those recommendations for which there seemed to be a consensus. Following each presentation was an open discussion that allowed participants to clarify their positions or to offer new ideas to the group.

A summary of the findings of the Kobe and Quito workshops follows. Here, as elsewhere in this report, there is a distinction made between *the GHI method*, which is an algorithm for assessing a community's earthquake safety, and the *GESI Pilot Project*, which is the eighteen-month pilot project designed to evaluate the GHI method's potential to improve earthquake risk management.

## Kobe Evaluation Workshop Summary (January 29-31, 2001)

### Results and Method

The workshop began with a session in which three groups evaluated the results and method of the GESI Pilot Project. The representatives of cities and international agencies were asked to evaluate the usefulness of the results to their respective constituents, in terms both of how the results might be used and how they could be made more useful. They were also asked what the implications the results might have for future development policies, and whether it seemed useful to separate out assessments of the school system.

#### *City Representatives*

The city representatives concluded that GHI method is easily understood with the potential to motivate long-term mitigation measures. They indicated that more attention should be given to the mitigation recommendations, that the results need to be better explained, and that the mitigation actions need to be prioritized so that resources are used efficiently. The group concluded that by interesting international development agencies, the project would indirectly motivate the cities as well. The city representatives believed that comparing cities in a region or country would provide more comprehensible results than the current comparison of a set of culturally and economically diverse cities. They also believed that separating out the schools was essential; it might also be useful to assess hospital systems separately.

The suggestions from the city representatives for improving the method focused on generating more useful results. The representatives emphasized that more explanation was needed to accompany the results to ensure that the conclusions had meaning to local decision makers. In addition, the graphical representations should be improved. As a tool for measuring the change in risk over time, the method should include a factor representing community involvement and general public awareness, the most effective means of reducing risk. In addition, the city representatives emphasized the need to validate the data to ensure that the results neither overestimate nor underestimate the risk. They were concerned that cities judged to have low risk might become complacent about the problem. It was believed that it would benefit the cities to circulate the results to the academic and professional communities, as well as to government agencies.

#### *International Agencies*

The representatives of international agencies agreed that the results are useful and will contribute to global risk reduction efforts by motivating both leaders and the general public. They believed that the project would be more useful in reducing risk by helping set priorities within a city than by ranking the cities, although they still considered the ranking to be valuable. In order for the GHI method to help their own agencies set global priorities, it should be applied to many more (e.g. hundreds) of cities. While they were concerned that the project did not address risk in rural areas, they acknowledged that half of the world's population is now urban and that being concentrated, it is now easier to address.

The representatives of international agencies believed that the results could be used in many different ways. They believed that the results would help illustrate mitigation options and rank them in order of importance. With proper dissemination, the city rankings could cause a temporary 'splash', but they would not ultimately be effective unless mitigation was emphasized. Without proper dissemination, the initiative could remain an ineffective, academic study, so it is critical to develop a clear strategy for disseminating the results locally and internationally. In addition, the risk to lifeline systems should be considered in each community and the results should be periodically updated to reflect the changing risk of each city. The participants agreed that if these issues are addressed, the GHI method would be an important public awareness tool.

*Technical Experts*

In the Results session, the technical experts were asked to evaluate the method and assess the reasonableness of the results. This session began with a detailed explanation of the method, augmenting the technical write-up that had been circulated to the participants before the beginning of the workshop (Appendix 2 is this write-up).

This group concluded that a loss estimation model is scientifically defensible. Conceptually, a comparison of risk between the cities is reasonable, and the specific comparison that was presented appeared reasonable. The group believed that the model needed refinement, and offered specific suggestions. These included investigating other indicators for shaking such as qualitative measures of shaking intensity (e.g. the "MMI" or the "MSK" scales), incorporating a shape factor to express the percentage of the city affected, and including separate estimates depending on time of day or as maximum and minimum possible losses. The latter suggestion was deemed especially important when working with the school system. Other suggestions included incorporating the likely effectiveness of search and rescue efforts by untrained neighbors as a function of building weight, and to account for the sequence of events in an earthquake to prevent the double counting of casualties.

*Plenary Session*

The Moderator summarized the findings of the three groups as follows. All groups found that the results are useful, with the evaluation of mitigation options being an essential part of the results package, and that it is critical how and where the results are presented. The method should be continually upgraded, with special attention to validating the data and controlling its quality. The general consensus was that the method needs to be expanded to include more cities, more communities within each city, more segments of society, and rural areas.

Following the summary, the participants discussed the sensitivity of the model to changes with time, errors in the data, and numbers of cities included. In order to be effective, the results should be disaggregated, made more specific, and combined with broad-brush cost-benefit analyses of mitigation efforts. However, the cost of further studies should be balanced against the cost of including more cities. It was suggested that the simplified loss estimation model that forms the basis for the method could be expanded to other risks. The final comments concerned the usefulness of the GHI method and its results. Participants thought that GESI could serve to inspire further study, to begin to measure mitigation efforts, to raise public awareness, and to help international aid organizations measure projects' effectiveness.

## Process

In the second session, the three groups were asked to evaluate the overall process used by the GESI Team, with particular emphasis on data collection and the use of 'official' and 'unofficial' data. Participants were also asked to discuss whether the results should be released privately or publicly and through what medium. The technical experts were also asked to propose alternate methodologies or ways of evaluating the project.

*City Representatives*

The city representatives concluded that it is best to use official data, augmented as needed by unofficial data, but subject to review by formal institutions (governments, institutions and universities) so the results will not be questioned. They acknowledged that this means that the data will be inconsistent in terms of both accuracy and precision.

Results should be released to the public after the data have been reviewed by the cities and modified, as appropriate. Although this may result in inconsistencies among the cities, the group decided that it was more important to have consensus within each city, and this is most likely to be achieved via an internal validation of the data and results.

The city representatives suggested improvements to both the data collection and the presentation of the results. For the data collection, they indicated that it is important to involve both formal and informal sectors, that answers should be scaled to reflect more than simply 'yes' and 'no', and that the data should be better explained so that respondents will understand the purpose of the questionnaires and how they will be used to generate results. In reference to improving the results, the city representatives indicated that it is important that the results, as presented, be labeled as preliminary until the different sectors in each city attempt to reach a consensus about their validity. They suggested that this would best be accomplished by a third visit to each city, through a regional workshop or through interactions with local organizations.

***International Agencies***

The representatives of international agencies also indicated that it would be best to use a combination of official and unofficial data and that it is important to qualify the present results as preliminary. They felt that the quality of any piece of data depends on its source, and every source has both strengths and weaknesses such as accuracy, expertise, political agenda, access to information, and subjectivity. They proposed that GHI serve as an unbiased assessor to resolve the data differences, choosing appropriate data based on best practices, while keeping the choices transparent by publicly explaining the data selection. When significant conflict remains about a particular value, the representatives suggested trying both and selecting the value that led to the best result or reporting the range of values.

In reference to the release of the results, the group thought that the current format is easy to understand. They suggested releasing the results in a workshop convened by a neutral source such as the UN where they could be thoroughly explained to prevent misunderstandings and associated complications. Before public release, it would be important to have a session to review and validate the data, and to get agreement among the various governments and agencies so that ownership for the project would shift to the cities. This validation and transfer of ownership would encourage cities to accept the results and agree to future assessments. The representatives thought that this should be the process for the present twenty-one cities. As the project scales up, it will be necessary to build further alliances; some of these were started at the Kobe Evaluation Workshop.

***Technical Experts***

In the second session, the technical experts were asked to independently assess the validity of the city rankings. The conclusion from this exercise was that experts would need a minimum data set including information about seismicity, the building stock population, and density order to make an independent assessment. Even with such data, the exercise as presented would validate only the procedure, not the data, and thus seemed neither necessary nor useful. As alternatives for this independent assessment exercise, they recommended assembling a different group of experts, applying a different loss estimation model to a subset of the same cities or conducting detailed city-specific analyses for a very few cities.

***Plenary Session***

Many ideas were suggested during the plenary session, expanding upon all those presented by the reporters. In reference to the expert-opinion ranking exercise, it was suggested that the comparison of cities might not be as important as the actual processes of data collection and result generation. With reference to official and unofficial data, it was pointed out that governments would never endorse unofficial data if it meant they had to respond to the underlying problems, so it seemed more important to pursue consistency and use similar sources from city to city. It was also reiterated that one of the strengths of the project is its ability to find and publicize the best available data, not limited to what is 'official' or endorsed. It was mentioned that it is important that both professionals and government representatives participate, the first to ensure the accuracy of the data and the second to instigate action.

## Future

In the third session, all three groups were asked to comment on the future of GESI, whether it should continue and if so, how it should be improved, how forecasts of mitigation efforts could be bolstered, and what role school assessment should play.

*City Representatives*

The city representatives concluded that the project should continue, and expand its focus to regional or countrywide comparisons. They indicated that the project should continue to assess the schools apart from the rest of the city, and should cover hospitals independently as well. They felt that the comparison is necessary, because it allows for the results to be presented in a positive manner, it establishes a baseline for data quality control, and it could be useful for the cities.

In terms of suggestions for overall improvements to the project, the group of city representatives found it essential to involve international organizations from the beginning of the project. They also felt that with the expansion to more cities, it would be necessary to decentralize the project, which would require training representatives in the method. The project would be more effective if it focused on the vulnerability and mitigation options of individual cities rather than on city rankings. Finally, the group thought that the effort required by the project could best be supported through an international fund.

***International Agencies***

The international agencies agreed that the project should continue, and that it needed to expand to many more cities. Their conclusion was that training representatives at regional focal points would accomplish this expansion by building local partnerships to collect data, with GHI continuing to compile and analyze the data.

In terms of motivating action, the international agencies indicated that the method should make general recommendations for risk reduction in cities and support the priorities determined by the cities instead of making specific forecasts or policy recommendations. About the project in general, they indicated the importance of periodically updating the rankings and city scores, of suggesting follow-up measures in specific sectors such as schools, and of seeking funding from international organizations such as the Japanese International Cooperation Agency (JICA), the Asian Development Bank (ADB), the US Agency for International Development (USAID), and the European Community Humanitarian Organization (ECHO).

*Technical Experts*

The technical experts presented similar findings. They agreed that the method should be applied to include more cities, with the benefit of being able to compare cities at the regional and local levels. They further suggested that the method should be expanded to allow for cost-benefit analyses of mitigation measures, that GHI should work at creating partnerships with local institutions and that GHI should improve the method as suggested in the first session.

***Plenary Session***

There was general agreement that the method is useful and will continue to be useful but needs to be applied to a much larger sample of cities. This would require a new process, with regional and national groups heading the data collection and results dissemination, while GHI handled the analysis and presentation of results. The decentralization of the general process will require increased attention to the data quality, with a new emphasis on uniformity and on the inclusion of both 'official' and 'unofficial' data. The group indicated that the results, even in abstract form, are useful, but that it would be better to disaggregate the mitigation measures. While the comparisons between cities were seen as useful, it should focus on comparing cities within a country or region or with similar socio-economic characteristics. GESI should continue to focus on the loss of life, but an improvement would be to add an indicator of the cost of mitigation measures. It is important that the data and results be periodically updated to capture the changing risk in each city.

## Conclusions

The fourth session of the Workshop differed from the first three in that it was not preceded by a working group discussion period. In this session, each of the three workshop leaders presented a ten-minute summary of one of the sessions, highlighting the major points and conclusions.

***Results***

Objectives:

- To determine if the results are useful to cities and international agencies,
- To understand how the results can be made more useful.

All groups agreed that the results are useful, and the GHI method can succeed in motivating risk reduction, raising awareness, and establishing funding priorities and strategies for resource use. In addition, the application of the GHI method to specific systems, such as schools and hospitals, is very valuable.

There were many suggestions for improving the usefulness of the results, including a continual update of the model. It was emphasized that the presentation of the results needs to be tailored to its stakeholders, which include the general public, local and national governments and international agencies. Validation of the data was stressed as a priority. The project should be expanded to include many more cities and other arenas, such as rural areas or specific regional concerns. Assessing the school system separately from the city as a whole was deemed necessary.

***Process***

Objectives:

- To review the quality of the data (both official and unofficial)
- To review the process of results dissemination
- To offer suggestions for improving the overall process followed in GESI.

One conclusion of the second session was that it was essential to ensure the accuracy of the data. To maintain the project's reliability when it expands to hundreds of cities and decentralizes, it will be important to familiarize everyone involved in data collection with the method. Official data should be used when possible; however, to maintain credibility as an independent assessment, the best available data should be used, even if this means using unofficial data. In all cases, it will be important to have the data set reviewed by formal institutions. To get the best possible data, it will be necessary to work with professionals, universities and government agencies.

The group determined that it is necessary to release the results, but they disagreed on whether the individual city representatives should first be notified. There was general consensus that continued and increased communications with the cities would be useful, and that the results should be released at the city level. Ultimately, it was believed that the best means of disseminating the results would be through a series of workshops convened by a neutral third party such as the United Nations.

Suggestions for improving the overall process included increasing the amount of explanation and training given to people involved in collecting data, and involving both formal and informal sectors in each city. The importance of building partnerships among different international, national and local agencies was also stressed.

***Future***

Objectives:

- To review recommendations for the future of the GESI project.

For the third session, the suggestions were grouped according to whether there was general agreement or lack of agreement.

All groups concluded that GESI should continue and that the current method was acceptable with modification. The emphasis on schools was important, and the effort should be extended to other sectors of the community. Risk management measures should be included. It was agreed that the method should be applied to many more cities, and that to accomplish this would require decentralizing data collection and building partnerships with local organizations. Finally, it was concluded that the project must commit to periodically updating the data sets and results and to publishing the updated findings through the UN.

Many issues were left undecided. Questions remained about whether to include rankings, and how to group cities when ranking them. There was no agreement on how to expand the project to more cities, and whether the method as well as the data collection should be decentralized. Finally, there was disagreement about whether and to what extent cost-benefit studies and policy recommendations should be included in the GHI method instead of being left to more detailed, post-assessment studies. It is important to continue to apply and develop the project even if perfect agreement could not be attained.

### Additional Comments and Addenda

The following thoughts and ideas were suggested during breaks and at other times in the Workshop:

- Cities' earthquake risks could be compared to risks from other hazards.
- Local earthquake professionals should be involved in dissemination so that they can present themselves as the concerned individuals in the city who are involved in addressing the problem.
- The x-axis of the "results" graphs could be used to provide additional information (e.g., discriminate among the cities according to their population).
- Use an integrated, multifaceted approach to publicize the results—TV, internet, newspapers, magazines, etc.

## Quito Workshop Summary (March 5-7, 2001)

### Results and Method

The workshop began with a session in which three groups evaluated the results and method of the GESI Pilot Project. The representatives of cities and international agencies were asked to evaluate the usefulness of the results to their respective constituents, both how the results might be used, and how they could be made more useful. They were also asked what the implications the results might have for future development policies, and whether it seemed useful to separate out assessments of the school system.

#### *City Representatives*

The city representatives indicated that it was essential to keep in mind GESI's goal: to motivate politicians and community members to improve their cities' earthquake readiness. They reinforced the idea that while the support of technical experts was important, the focus should be on those people who can implement change. They believed that the project succeeded in rapidly producing inexpensive results that are valid and reasonable, but that the project will need to be repeated periodically so that progress can be monitored.

They recommended developing different ways to present the results to target different audiences such as scientists, technical experts, politicians and children. Because the city representatives thought education should be a major emphasis of the project, they suggested including children in the process, adding a school-age curriculum on risk to the results package and that evaluating systems such as schools and hospitals was essential. Since GESI is intended as a pro-active project working on prevention, the group indicated that it would be helpful if the indicators were designed to be themselves directly applicable to planners.

#### *International Agencies*

The representatives of the international agencies focused first on the usefulness of the results and concluded that the results were only useful to international organizations in so far as they were useful to cities. Thus the project should emphasize the city-specific mitigation suggestions, and de-emphasize inter-city comparison. The representatives felt that for the results to be useful to the cities, cost-benefit analyses of the risk mitigation options should be included. They argued that with these improvements, the GESI project would help both to attract resources to cities and to better allocate existing resources. In terms of both the validity and the usefulness of the results, the representatives of the international agencies thought that the project should include the training of professionals in the various sectors (health and schools) in risk reduction and educational tools. They themselves could help coordinate these sector-specific efforts. In the future GESI might be used for post-earthquake analysis, and to help the reconstruction process.

The representatives from international agencies thought it essential to empower local politicians by seeking their input and involvement. With work, the GHI method could be used as a tool both for raising awareness and for creating and supporting a network of earthquake mitigation activists.

With regard to the presentation of the results, the representatives of international organizations emphasized that the results should be simple and clear, and that an understandable description of the method should be included. Comparisons of cities with similar cultures and economies could be useful, but since the results could be sensitive, their proper interpretation should be carefully explained.

***Technical Experts***

The technical experts were asked to evaluate the method and to assess the reasonableness of the results. The session began with a detailed explanation of the existing method that augmented the technical notes that had been circulated to the participants before the beginning of the Workshop (Appendix 2 is a copy of these technical notes.).

The technical experts approved of the project's integration of prevention, preparation and mitigation, however, they argued that loss of life would not be a motivating force for politicians, because, for the most part, elected officials are insensitive to this indicator. They urged that the method be reviewed to assure that all assumptions were based on conditions in developing nations.

More specifically, the technical experts believed the project should include socio-economic indicator. They thought that in Latin America the Modified Mercalli Intensity (MMI) scale would make better use of available information than PGA as a measure of hazard. They believed that only the per capita risk results should be presented, and that more work should be done assessing building vulnerability, for example including a wider variety of structural types and local materials. The technical experts also thought that it was important to evaluate the loss associated with various spectra of input ground motion in order to model different types of earthquakes.

In conclusion, the group of technical experts said that it was essential that the GESI results support a "bottom-to-top" approach to risk mitigation. To this end, it should not be a theoretical approach, but grounded in direct application. They saw the GESI project as a useful method for local people to begin the process of risk mitigation, with one strength being its ability to be modified by local users. Like the other groups, the technical experts also indicated that it is essential to keep the project's users constantly in mind so that the results will be tailored to meet their needs and appeal to their concerns.

***Plenary Session***

The Moderator of the Plenary Session summarized the findings of the three groups by first recalling that the ultimate users of the results would be political leaders, community members and educators. Important recommendations for the method had emerged from the technical evaluation, and he restated the emphasis on parameter validation. All groups agreed that GESI served a valuable role focusing attention on prevention and planning, and some even argued that it could aid in post-earthquake assessment and reconstruction.

**Process**

In the second session, the three groups were asked to evaluate the overall process used by the GESI team, with particular emphasis on data collection and the use of 'official' and 'unofficial' data. Participants were also asked to discuss whether the results should be released privately or publicly and through what medium. The technical experts were also asked to propose alternate methodologies or ways of evaluating the project.

***City Representatives***

The city representatives thought that GESI would bring local communities together with international organizations who could act as liaisons between data collectors and local experts. They thought that it was essential to consider local socio-economic situations in all aspects of the project, including data collection, results dissemination and estimation of risk mitigation costs. Local studies should be included in the data, and immediate actions should be suggested as early as the interview process. To ensure that the results are used, politicians should be included in the data collection. Finally, the results should be presented in diverse ways.

Concerning the questionnaires, the group of city representatives thought that there needed to be more questions that invited a range of values instead of only "yes" or "no." The questions should also be more targeted, and should include questions on non-structural risks and on lifelines such as water, sewage and power. There should be questionnaires for politicians both to involve them and so that their positions are clearly understood. The city representatives believe that both unofficial and official data should be used, and that these data should be collected in a workshop where the method can be explained. The group determined that local professionals would be in the best position to know effective modes of result dissemination that would also be sensitive to local politics, and that the GESI project could have an added benefit of spurring local studies.

***International Agencies***

The representatives of international agencies indicated that it was important to involve all sectors of society in the collection and analysis to ensure the reliability of the data, to promote risk awareness, to reduce gaps in the data and to validate the results. City representatives should be trained in data collection, and in the method. The representatives thought that cost-benefit analyses of risk mitigation efforts would be useful to both the city and bilateral agencies. The representatives of international agencies thought that they could assist GHI with coordinating the different approaches that will be required in each city.

The representatives of the international agencies believe that as long as GESI remains a transparent assessment tool, it will be possible to use both official and unofficial data. It will be necessary to negotiate with local officials to reconcile official and unofficial data, but coordinated workshops and good communication will help. The representatives of the international agencies re-emphasized that the results should be aimed at motivating politicians and local decision makers, and that to gain their confidence it will be important to host workshops to explain the process and method in advance. International organizations could help by hosting these workshops, collecting data and helping with local method development.

The international agencies thought that local city people would be in the best position to oversee the dissemination of the results, but that networks maintained by the international organizations could be valuable resources. They thought that the results should be disseminated through as many different media as possible, such as CD-ROM, the internet, Risk Atlas, and a text book documenting the best risk reduction practices. They also thought that it would be useful to organize small meetings and seminars, targeting especially vulnerable sectors such as schools and health systems.

***Technical Experts***

The technical experts concluded that it would be essential to involve the political system in the production of the data and results so that the results would exist within the political system rather than outside it. This would motivate participation and discourage leaders/politicians from ignoring embarrassing results. They reiterated the importance of including socio-economic indicators and thought that a natural spin-off of the project might be an international data bank for information about local, national and regional risk. The technical experts stated that the results should be disaggregated so as to be more useful to the user-clients with different interests. They suggested a matrix including an 'importance factor' for cities with particular cultural, historical, or religious significance. The group suggested that a group of regional experts could validate the results by compiling an alternative comparison set using "fuzzy set" theory.

***Plenary Session***

The Plenary Session started with the Moderator reiterating the need to present results in a manner useful to the ultimate users. Further suggestions included developing socio-economic indicators and cost-benefit analyses of mitigation actions. There was interest in providing immediate short-term actions to local people during the data collection process, and in collaborating with international organizations in the data collection process. The group suggested that policies should be defined concerning the process of results dissemination. The group as a whole indicated that it saw the possible uses of the GHI method increasing in the future.

## Future

In the third session, all three groups were asked to comment on the future of the GESI project, whether it should continue and if so, how implementation should be improved, how forecasts of the effects of mitigation efforts could be improved, and what role school assessment should play in future generations of the project.

***City Representatives***

The city representatives examined ways to improve data collection and presentation of the results. They thought that the questionnaires needed to be modified to include politicians' views. They also indicated that local institutions should have the chance to review the data before the results are officially released, and that workshops should be added before the preliminary results are finalized to check the data and to collect any further necessary data. They thought data should be collected by local technical groups thoroughly trained in the method, so that there will be local ownership of the project and so that the results can be defended.

The city representatives stated that it was essential to raise awareness among local authorities and within the community, possibly by increasing communication. They indicated that the project is well suited for this as it provides a global view of the problem, is non-technical, and offers suggestions to decision makers. The representatives worried about continuing to rely on work provided voluntarily by people who receive funding from governments and universities, and who may be restricted by their responsibilities. They indicated that international funding would be necessary to ensure the necessary quality of the work in the future.

They hoped that in the future, GESI would expand to cover all countries threatened by earthquakes, that it would incorporate local research and measure local actions, and that the risk between similar cities would be compared. They also suggested that GESI be used to create a pervasive culture of risk awareness by educating school children and by hosting periodic meetings, by updating cities' risk and by encouraging mitigation.

***International Agencies***

The group of international agencies stated that they thought that GESI had the potential to motivate local action, and that they approved of its focus on prevention and mitigation. They believed that there could be a large, diverse group of users, and that decision makers would see it favorably. They indicated that the process could be improved by including cost benefit analyses or cost-effectiveness ratio for risk management efforts. They liked the focus on the overall risk of the schools, and saw benefit of repeating the process for schools, and thought it should be expanded to cover hospitals as well. They also believed that there was value in comparing the risk of cities, especially on the sector-specific scale, and saw that this would benefit both international organizations and national decision making bodies.

For the future, the international agencies suggested that the project should be repeated in Latin America and the Caribbean, concentrating on the cities that have already been assessed. They indicated that the method should be revised and updated to include hospitals and other recommendations made during the two Workshops. They believed that to make GESI more successful, it will be important to work closely with local people to assess the cost effectiveness of mitigation efforts and to help them understand the results.

***Technical Experts***

The group of technical experts believed that GESI could motivate action and promote a culture of risk awareness through on-going educational endeavors. They indicated that the GHI method could be an effective tool for training groups in mitigation and prevention by identifying needs and promoting action. They believed that in this capacity, the results would be more useful if they were disaggregated and presented to end users in an understandable language. They reiterated that the results should indicate trends and suggest mitigation actions, but that the results were diagnostic rather than prescriptive.

Further suggestions from the technical experts included disseminating the results through a web page, and creating a regional risk database. They believed that there would need to be better coordination among the different sectors of scientists and planners to create a common language of risk reduction, and they hoped that the GHI method could serve in creating this language. It would be important to train local teams in the application of the results, and further empower these local teams, possibly by creating a regional umbrella organization with local representatives that would act as a clearinghouse for city experiences. The technical experts indicated that some socio-economic indicator should be included that would impress politicians, and that a cost analysis must accompany the risk mitigation efforts. They thought that vital systems such as transportation should be included in the sector-specific studies along with hospitals and schools, and that all of these sectors should be studied in more detail. In terms of validation, there was a suggestion that the El Salvador earthquakes be used to validate the method.

***Plenary Session***

There was a great deal of debate during the Future Plenary Session. Many people felt that it was not as important to revisit the cities included in the GESI Pilot Project as it was to expand to new cities. Others believed that the project should culminate in a textbook of best practices, which would suffice as the final output. There were suggestions to conduct simultaneously more in-depth studies of the first round cities while adding more and more cities. This could be aided by adopting a training mentality, where GHI would act as a trainer of trainers. More training was encouraged across the board, to help empower local experts to defend and explain the results, and to tailor the documents to location. There was some discussion of training one of the ultimate end-users—masons—and on the importance such actions can have for reducing risk.

Specific, tangible actions appealed to people, as did the potential of GESI to motivate action on a grassroots level. It was suggested that communities that have recently suffered from earthquakes be targeted; they are more likely to have the political will to make changes. It was thought that suggestions of good mitigation actions should be made as early as the interview stage so that local people could begin to see results. Furthermore, there should be some forum for cities to exchange experiences and lessons.

## Conclusions

The fourth session of the GESI Workshop differed from the first three in that it was not preceded by a working group discussion period. In this session, each of the three workshop group reporters presented a ten-minute summary of one of the plenary sessions, highlighting the major points and conclusions.

***Results***

Objectives:

- To determine if the results of GESI are useful to cities and international agencies,
- To understand how the results can be made more useful.

The results were reviewed to determine their reasonableness and usefulness to both the cities and international organizations. As an inexpensive, quick assessment tool, GESI was believed to produce reasonable results that could motivate both decision makers and community members. For it to achieve this, the expression of the results should be adapted for particular audiences. The project will be useful insofar as it is useful to cities; therefore emphasis should be placed on the application side of the project: cost-benefit analyses of various mitigation options should be included, and the local socio-economic situation should be considered in presenting these mitigation options. There was general agreement that the project should expand to include more system-specific studies such as of hospitals and transportation networks, and that regional organizations such as the Pan American Health Organization (PAHO) could help with data collection and result dissemination. In terms of validation, it was suggested the recent events in El Salvador could help reveal GESI's ability to identify and quantify city vulnerabilities.

Comparisons among cities with similar socio-economic situations or within the same nation were seen as useful, and the group indicated that the project might indicate solutions that could be applied on the national level. The comprehensiveness of the method was praised, in particular the combination of the technical and humanitarian sectors, and all agreed that the focus on prevention and preparedness was essential. There was concern that fatality figures would not motivate decision makers. While there was concern that some of the baseline information was based on conditions found in industrialized nations, it was not certain that the corresponding information would be available in developing communities, and the group wanted to be sure that local structural practices were taken into account in the method.

***Process***

Objectives:

- To review the quality of the data (both official and unofficial)
- To review the dissemination of results
- To offer suggestions for improving the overall process of GESI.

With regard to the process of data collection and results dissemination, the participants thought that it would be useful to involve more of the community. Training local people in both the data collection and the results dissemination would result in a more useful project. The group suggested that the international organizations should take a more active role, as they not only have a great deal of information, but they also can act as catalysts for change. The group indicated that for the project to have long-term success, it would be important for GESI to be supported by a regional organization with knowledge of the cities.

In terms of overall improvements to the project, it was stated that the project would be more motivational if it included socio-economic indicators, but these should not come at the cost of the humanitarian aspect. The project's ability to include other sectors should be explored. It might be particularly useful to cities if it could indicate neighborhoods at special risk. They suggested that actions that can be taken immediately should be suggested during the data collection phase of the project, and that it will be an ongoing project to identify the best mechanism for result dissemination in each city.

***Future***

Objectives:

- To review recommendations for the future of the GESI project.

The recommendations for GESI's future were separated into those to be done in the short term, and those to be done in the long term. In the short term, preliminary results should be made final. As well, it would be necessary to review and modify the questionnaires and add a questionnaire for local politicians. In the short-term it was seen as important to train local representatives in the project method to transfer ownership of the project to the cities, and to identify a regional organization to act as a focal point. On the topic of results dissemination, it was suggested that the results package be modified to include cost-benefit analyses, that a final report on the findings of the pilot project be published, that a home page dedicated to GESI be created and that relationships with international organizations be initiated. It was thought that in the short-term a plan should be drafted concerning how the results will be implemented in the cities, and that it would be beneficial to host a workshop in the cities to explain the results and help design an action plan.

Long-term suggestions included the development of a separate GHI method that could be applied to the hospital and health care sectors, and to apply the method to more cities. Some participants suggested that socio-economic indicators should be integrated into the method and that a validation of the data, analysis and results should be conducted. In the long term, they indicated that it would be possible to set up programs to train local representatives in the method to apply the method to more communities, which would help raise awareness, educate people about risk and disseminate implementation options. The participants indicated that many of these actions would have the secondary benefit of increasing the mitigation resources available to cities.

## Additional Comments and Addenda

Many thoughts and ideas were suggested during breaks and at other times in the workshop. In addition, people who were not able to attend the workshop submitted written comments. We have attempted to include as many ideas as possible that were not included earlier in the discussion.

- The definition of the population should be expanded to include floating populations (people who do not live full time in the city, or who only work there).
- More consideration should be given to construction practices on infill land.

- The people interviewed for data should be selected carefully.
- The media should be educated about the project and the limitations of its results before they are allowed access to those results for publication.
- It is important to include concrete solutions in the results package.
- Both a short-term and a long-term PGA value should be used, such as a 100-year return period value as well as the 500-year return period.

# Contents of enclosed CD-ROM

The Global Earthquake Safety Initiative (GESI) Pilot Project applied the GeoHazards International (GHI) method of assessing community earthquake safety to twenty-one cities worldwide to evaluate its potential to improve earthquake risk management. The GESI Pilot Project spanned eighteen months, from January 2000 to June 2001 and was conducted by the GESI Team, which was formed by staff from GeoHazards International, the Disaster Management Planning Office of UNCRD, and the University of British Columbia.

This disk contains the City Risk Summaries for the 21 cities that participated in the GESI Pilot Project.

- Antofagasta, Chile
- Bandung, Indonesia
- Delhi, India
- Guayaquil, Ecuador
- Islamabad and Rawalpindi, Pakistan
- Istanbul, Turkey
- Izmir, Turkey
- Jakarta, Indonesia
- Kathmandu, Nepal
- Kobe, Japan
- Manila, Philippines
- Mexicali, Mexico
- Mumbai, India
- Nagoya, Japan
- Quito, Ecuador
- San Salvador, El Salvador
- Santiago, Chile
- Tashkent, Uzbekistan
- Tijuana, Mexico
- Tokyo, Japan
- Vancouver, Canada

# System Requirement

Hardware requirements:

-CPU: Pentium 75 MHz or above

-Memory: 24 MB RAM or above

-Display Setting:

Color: High color (16 bit) or above

Screen Display: 800 x 600 or above

Software requirements:

-Operating System: Windows 95, 98, ME, NT4.0, or 2000

-Web Browser: Internet Explorer 4.0, Netscape 4.0, or later

-Application: Acrobat Reader 4.0 or later

# Getting Started

1. Insert the GESI City Report CD-ROM into your CD-ROM drive, then the top-page will be opened automatically.
2. If it does not work automatically, double-click "top-page.htm" in the "bin" folder.

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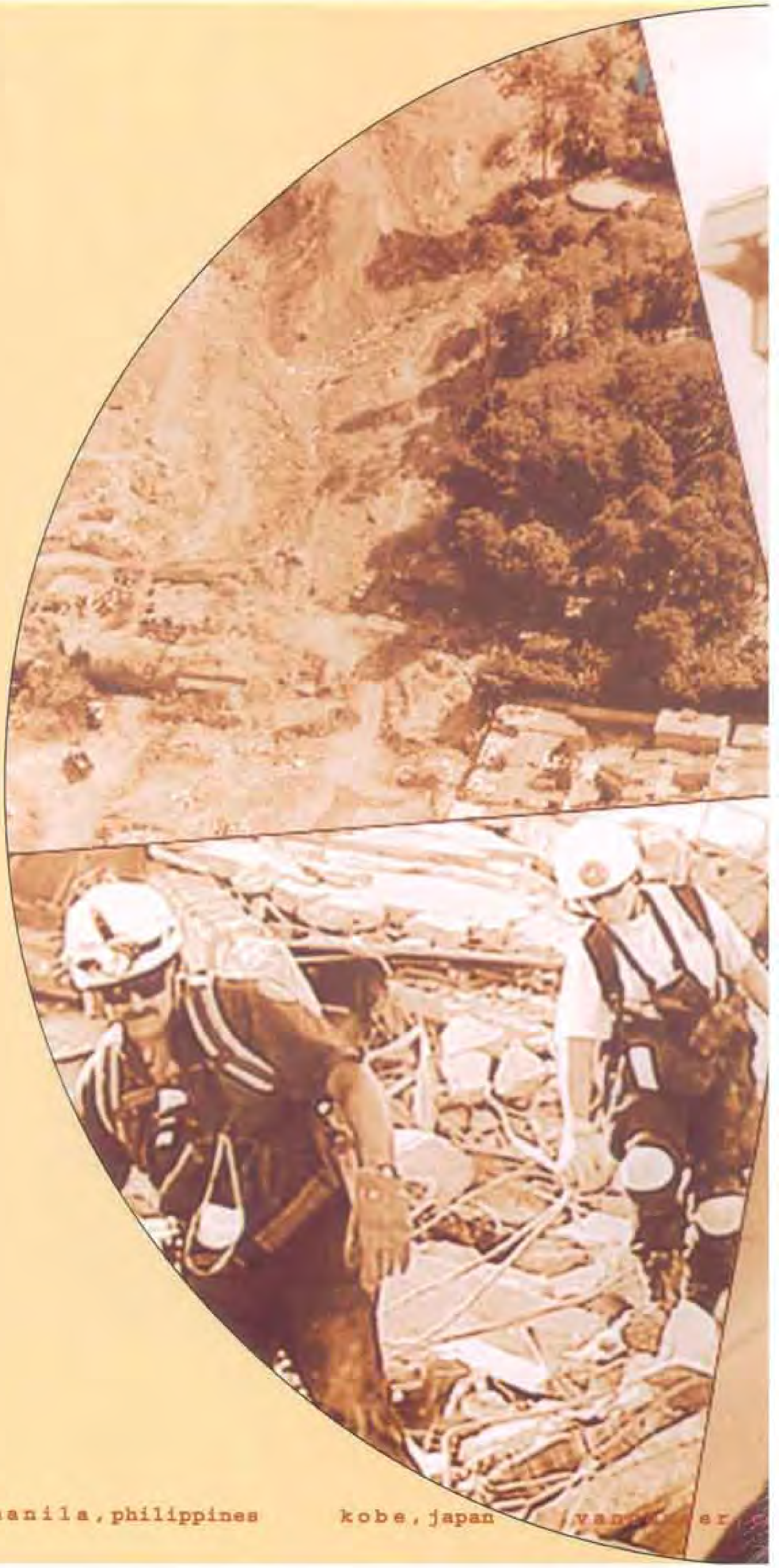
japan    tashkent, uzbekistan    istanbul, turkey    nagoya, japan



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