Urban Disaster Management:

A Case Study of Earthquake Risk Assessment in Cartago, Costa Rica

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(Met een samenvatting in het Nederlands)
(Con un Resumen en Español)

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- Dr. M.K. McCall
- Prof. Dr. W.H. van den Toorn
- Prof. Dr. O. Verkoren

To John and the Montoyas

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Note: all figures are the original work of the author unless otherwise stated.

List of Acronyms

ACI	American Concrete Association
ADB	Asian Development Bank
ASTM	American Society for Testing of Materials
ATC	Applied Technology Council
BCR	Benefit-Cost Ratio
CATIE	International Centre for Tropical Agriculture (Costa Rica)
CBO	Community Based Organisation
CEPREDENAC	Centre for the Prevention of National Disasters in Central America
CFIA	Federated Board of Engineers and Architects (Costa Rica)
CNE	National Commission for the Prevention of Risks and Response to Emergencies (Costa Rica)
CRED	Centre for Research on the Epidemiology of Disasters
DEM	Digital Elevation Model
DIN	Disaster Information Network
DMC’s	Developing Member Countries (of Asian Development Bank)
DPM	Damage Probability Matrix
DV	Digital Video
EDRI	Earthquake Disaster Risk Index
EMS	European Macroseismic Scale
ERD	Earthquake Resistant Damage
FEMA	Federal Emergency Planning Agency
GAM	Greater Metropolitan Area
GDIN	Global Disaster Information Network
GDP	Gross Domestic Product
GIS	Geographic Information System
GNP	Gross National Product
GPS	Global Positioning System
HAZUS	Hazards United States: Software for standardized, national methodology for assessing losses from natural hazards.
IDNDR	International Decade for Disaster Reduction
IFAM	Institute for the Assistance and Stimulation of Municipalities (Costa Rica)
IGAC	Instituto Geográfico Agustin Codazzi (Colombia)
IGN	Instituto Geográfico Nacional (of Costa Rica)
IKONOS	First commercial satellite to collect images with one-meter resolution. IKONOS is derived from the Greek word for "image."
INEC	National Statistics and Census Institute (Costa Rica)
INS	National Insurance Institute (Costa Rica)
INVU	National Housing and Urbanism Institute (Costa Rica)
ITC	International Institute for Geo-information Science and Earth Observation
ITCR	Technological Institute of Costa Rica

JPG	Image file Extension: JPEG Joint Photographic Expert Group
MDF	Mean Damage Factor
MIDEPLAN	Ministry of Planning and Economic Policy (Costa Rica)
MINAE	Ministry of Natural Resources and the Environment
MINVA	Ministry of Housing and Human Settlements (Costa Rica)
MMI	Modified Mercalli Intensity
MMWR	Morbidity and Mortality Weekly Report
MOPT	Ministry of Transport (Costa Rica)
MS	Ministry of Health (Costa Rica)
MSK	Medredev-Sponhhuer-Karnik
NCIP	National Capital Investment Program
NDIN	National Disaster Information Network
NETC	National Emergency Training Center
NGO	Non-Governmental Organisation
NIBS	National Institute of Building Sciences
OAS	Organisation of American States
PESH	Potential Earth Science Hazards
PGA	Peak Ground Acceleration
PROCIG	Central American Project for Geographic Information
RECOPE	Government-owned Costa Rican Petroleum Refinery
RMS	Risk Management Systems Corporation Inc.
SEN	National Statistics System (Costa Rica)
SICA	Central American Integration System
TIFF	Image file Extension: Tagged Image File Format
UCR	University of Costa Rica
UN	United Nations
USGS	United States Geological Survey
WWW	World Wide Web

Chapter One: INTRODUCTION

This chapter describes the thematic context of the study, the main problem to be addressed and the research objectives. In terms of the thematic context, the effects of natural hazards in urban areas are documented. It addresses the need to produce forecasts of possible loss (of human life and property) attributable to the different hazardous events that could take place, in order to establish the cost-benefit of alternatives and ensure successful urban policy policies and adequate economic resource allocation.

1.1 HAZARDS IN URBAN AREAS

Hazards are part of the environment in which we live. It is impossible to live in a totally hazard-free environment since each day one inevitably faces some degree of personal risk from road accidents, fire, theft, floods, etc. A hazard can therefore be defined as a threatening event.

Some authors classify hazards according to the triggering reason: *voluntary* hazards (e.g. smoking, paragliding) and *involuntary* hazards (e.g. fire, earthquake). Others classify hazards into three classes according to their nature:

- *Technological* hazards are those accidental failures of design or management affecting large-scale structures and transport systems, or industrial activities that present life-threatening risks to the local community (Smith 1996).
- *Natural* hazards result from those elements of the physical environment harmful to Man and caused by forces extraneous to him (Burton et al. in Smith 1996).
- *Human-induced natural* hazards are those that are caused by the human modification of the environment.

Threats posed by hazards are classified by the type of loss they cause (see Table 1.1): *direct* (or primary) losses and *indirect* (or secondary) losses. They are also categorised according to their potential effects (see Table 1.1): hazards with a) *social or human* effects, b) with *physica*l effects and c) with *economic* effects.

Natural hazards are dynamic and uncertain processes – *dynamic* because they do not always happen in isolation (as one event could trigger another, e.g. an earthquake could trigger a landslide) and because they can reshape the environment; *uncertain* because their occurrence is generally difficult to forecast. Natural disasters can be defined as the impact of natural hazards upon a vulnerable community, resulting in disruption, damage and casualties that cannot be relieved by the unaided capacity of locally-mobilised resources (United Nations Disaster Relief Co-ordinator 1991). Smith (1996), however, points out that there is no universally agreed definition of the scale on which loss has to occur in order to qualify an event as a disaster, although most disasters do have a number of common features:

- The origin of the hazardous event is clear and produces characteristic threats to human life or well-being (e.g. a flood causes death by drowning).
- The warning time is normally short; hazards are often rapid-onset events. This means that occurrences can be unexpected even though they occur within a known hazard zone, such as the floodplain of a small river basin.
- Most of the direct losses, whether of life or property, are suffered fairly shortly after the event, typically within minutes or hours.
- The exposure to hazard, or assumed risk, is largely involuntary, normally due to the location of people in a hazardous area, such as the unplanned expansion of cities onto unstable hill slopes.
- The disaster occurs with an intensity that justifies an emergency response, such as the provision of specialist aid to victims. The scale of response can vary from local to international.

	Social or Human Effects	**Physical Effects**	**Economic Effects**
Primary Effects	- Fatalities - Injuries - Loss of income or employment opportunities - Homelessness	- Ground deformation and loss of ground quality - Collapse of and structural damage to buildings and infrastructure - Non-structural damage, loss of ground quality for buildings and infrastructure	- Interruption of business due to damage to buildings and infrastructure - Loss of productive workforce through fatalities, injuries and relief efforts - Capital costs of response and relief
Secondary Effects	- Disease or permanent disability - Psychological impact of injury, bereavement, shock - Loss of social cohesion due to disruption of community - Political unrest where government response is perceived as inadequate	- Progressive deterioration of damaged buildings and infrastructure which are not repaired	- Losses borne by insurance industry, weakening the insurance market and increasing premiums - Loss of markets and trade opportunities through short-term business interruption - Loss of confidence by investors, withdrawal of investment - Capital costs of repair

Table 1.1: Potential Effects of Natural Hazards (Solway 1999)

According to projections made by the United Nations in 1996, by the beginning of the XXI century, half of the world's population will live and work in urban areas and, according to projections, the percentage of urban dwellers and urban workers will continue to increase during the XXI century (see Figure 1.1).

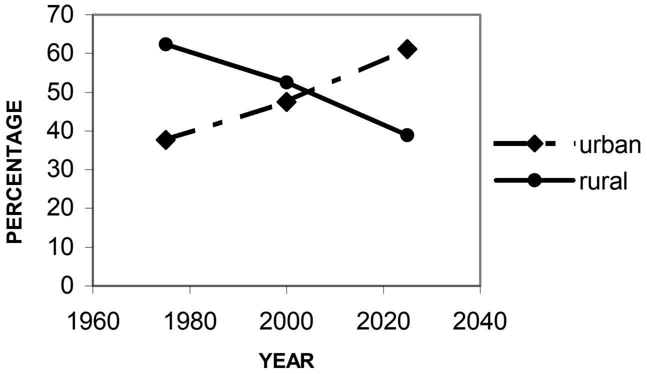


Figure 1.1: World Urbanisation Trends (United Nations Centre for Human Settlements 1996)

By concentrating population, buildings, infrastructure and economic activities into small areas, the greater interplay between the different urban elements that exist creates higher vulnerability indices compared with the same elements widely spread in a rural environment. A multiplying effect occurs in urban areas and, therefore, losses due to natural hazards are usually much more severe than in rural areas. For this reason, more than ever before, the issues of urban planning and disaster management are crucial in ensuring adequate social, economic and environmental conditions.

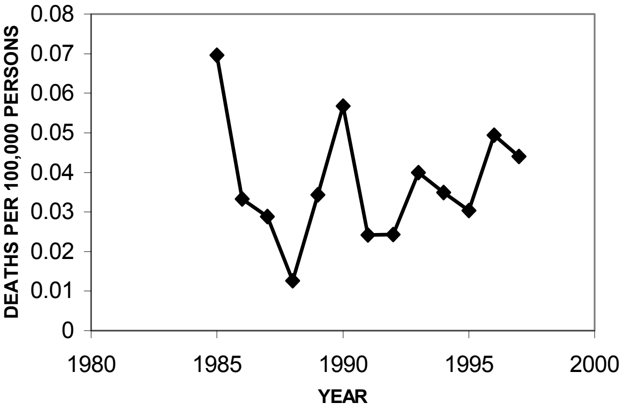


Figure 1.2: Deaths per 100,000 Inhabitants through Floods in the USA
(data sources: US Census Bureau (1999) and US National Weather Service (1985-1996)

It must be noted at this point that it is not the researcher’s intention to adopt the apocalyptic view that others have. While it is correct to say that there has been an increase in disaster losses, it is important to keep in mind that there has also been an increase in the population and, consequently, an increase in the number of “urban elements” and therefore of “elements at risk”. For example, a rate of damage depicted as “3.4 casualties per 100,000 population in Alameda County” (MMWR 1989) is here considered the correct way of depicting losses, as only through relative figures can conclusions be drawn. Moreover, as can be observed in Figure 1.2, the mitigation measures already implemented throughout the world have proved to have prevented the rate of deaths resulting from natural disasters from increasing. Due to improved weather warning systems, there seems to be a worldwide trend towards a considerable reduction in loss of life – especially loss through floods, landslides and hurricanes. However, this trend does not apply to property damage. This phenomenon highlights the problem of uneven effort and research in some areas.

Stage	**Time Relative to Event**	**Reaction**	
		Positive	**Negative**
1	Before event	Understand warnings, preparedness	Panic, fear
2	During event	“What should we do?”	Fatalism, “Act of God”
3	1 min. to 1 day after event	Response by survivors, initial search and rescue	Looting, sight-seeing adding to traffic chaos
4	1 day to 1 week after event	Community effort, search and rescue by emergency services	Increase in price of basic food and commodities
5	1 week to 1 month after event	Provision of temporary camps, burial of dead, analysis of problems	Provision of wrong food and medicine, disposal of dead
6	1 month to 1 year after event	Clear up debris, commitment to major rehabilitation projects, international funds	Provision of unsuitable and unacceptable temporary accommodation, allocation of blame, corruption and misuse of emergency funds
7	1 to 5 years	Some mitigation work, some progress on rehabilitation	No visible evidence of damage, bureaucracy and aid fund accountability delays rehabilitation and reconstruction
8	5 to 30 years	Increased mitigation work, review preparedness and response programmes	Conflicting objectives lead to relaxation of building regulations to reduce cost of social housing, smaller event produces same effect on target city
9	Until next major event in 100, 200 or 500 years	Steady programme of mitigation work	“Not happened in my lifetime”, no votes for mitigation, funding reallocated

Table 1.2: Human Reactions to Natural Disasters (adapted from Solway 1999)

A paradox exists, however, between the outstanding achievements in science, which make life safer and healthier (and have made it possible to land men on the Moon and clone both plants and animals), and the slow reduction in the rate of damage attributable to “natural hazards” and the horrific rise in the number of deaths from the AIDS virus in Africa. The paradox is complicated by the fact that science itself is not without hazard and has led to the relatively recent “man-made” threats caused by the failure of technological systems, the catastrophe at Chernobyl (1986) and the oil spill from the Juan Valdez in Alaska (1989) being two good examples. The paradox is further complicated by the social perspective (see Table 1.2). As Solway (1999) pointed out, interest in disaster preparedness is proportional to the recency and magnitude of the last disaster that took place.

Natural disasters can destroy decades of human effort and investment. Since natural disasters can have a strong negative impact on long-term development, they are a threat to sustainable development. In addition to the direct social and economic impact, natural disasters affect employment, the balance of trade and foreign indebtedness for years after their occurrence, and funds intended for development are often diverted into costly relief efforts (Organisation of American States (OAS) 1991). Following Hurricane Caesar (1996), the Costa Rican government suspended the National Census in order to divert the funds into the reconstruction of bridges and road sections that had been destroyed or damaged. According to Tucker, Trumbull et al. (1994), earthquake-caused fiscal losses represent a greater percentage of the gross national products (GNP) of developing countries than of developed countries. For example, the 1972 Managua earthquake cost US$ 5 billion and represented 40% of Nicaragua's GNP, while the Northridge (Los Angeles) earthquake caused losses of US$ 30 billion, which represents less than 1% of the USA's GNP and about 8% of the GNP for the Greater Los Angeles area.

According to ISL (1999), the economic losses attributed to the Turkish earthquakes of 1999 have reached as high as US$ 30 billion, costing the Turkish government 1% of its GNP in 1999 and 2% in 2000. Parker, Kreimer et al. (1995) consider that more meaningful than the comparison of earthquake expenditure with GNP is its comparison with the National Capital Investment Program (NCIP). Capital for development projects and infrastructure is a valuable resource and essential for development planning. The total cost of the Turkish earthquake of 1983 was equivalent to just under 2% of the entire 1983 NCIP for Turkey. A sum equivalent to the cost of the earthquake, 2% of the NCIP, was spent on public housing throughout Turkey in 1982. Slightly more than 2% was invested in public health services, while educational facilities accounted for just over 4%. In this context it can be seen that the loss of similar sums of money to replace the damaged building stock is a severe penalty that drains funds needed elsewhere and can slow down the country's economic development.

Benson (1998) believes that as one moves from developing to highly developed economies, the nature of a disaster's impact alters. The absolute cost of physical damage increases but its relative cost (as a proportion of national or local wealth) decreases; and the number of lives lost also declines. For example, in the USA Hurricane Andrew (1992) caused damage estimated at US$ 22 billion (equivalent to 0.3% of GNP) but only 14 people lost their lives. In contrast, in the Philippines Typhoon Angela (1995) caused losses of US$ 63 million (equivalent to 0.1% of GNP) but the death toll reached 916. It is estimated that per capita losses of the GNP in developing countries are 20 times greater than in the developed countries (Clarke and Munasinghe 1994). The somewhat extreme examples of Bangladesh and Turkey help one to understand the meaning of disaster losses for the economy of a less developed country. According to Rahman (in Caballeros Otero and Zapata Martí 1994), more than 5% of Bangladesh's GNP is lost annually to recurrent natural disasters. Erdik (1994) pointed out that Turkey annually allocates, on average, about 1.5% of its national budget just for rural housing construction after earthquake disasters.

The greater losses through natural disasters in the developing world highlight differences in terms of the weakness of the economies, the perception of people towards natural disasters and the scant attention that has been paid to disaster management. For example, Tucker, Trumbull et al. (1994) illustrate the disparity between earthquake threat and earthquake mitigation effort in developing and developed nations by analysing the number of attendees at the World Conference of Earthquake Engineering over a period of 35 years. While the ratio of attendees from developing countries has remained approximately constant, for developed nations the value has increased 400-fold. Unfortunately, as pointed out by Mitchell (1998), until very recently, disaster management and long-term development tended to be seen as distinct entities instead of being inextricably linked and part of the same ongoing process. Moreover, in many countries disaster response has been the only form of disaster management carried out. The Yokohama Message stated “disaster response alone is not sufficient, as it yields only temporary results at a very high cost. We have followed this limited approach for too long” (United Nations 1994).

Waugh (2000) points out that disaster management involves actions and demands resources beyond the means of individuals and family groups. Indeed, threats to life and property from nature and from humankind encourage the development of communities to pool resources in order to find common solutions.

Disaster management should consist of an organised effort to mitigate against, prepare for, respond to, and recover from a disaster (Federal Emergency Management Agency, National Emergency Training Center et al. 1998). The following definitions describe each of the phases of this disaster management cycle (see Figure 1.3):

- *Mitigation* relates to pre-activities that actually eliminate or reduce the chance or the effects of a disaster. Mitigation activities involve assessing the risk and reducing the potential effects of disasters, as well as post-disaster activities to reduce the potential damage of future disasters. Examples of mitigation mechanisms include land-use regulations, engineering works, building codes and insurance programmes.
- *Response* refers to activities that occur during and immediately following a disaster. They are designed to provide emergency assistance to victims of the event and reduce the likelihood of secondary damage. Response activities include search and rescue, evacuation, emergency medical services and fire-fighting, as well as reducing the likelihood of secondary effects, for example to the contents of damaged buildings. Local government officials, as well as the community itself, constitute the ”first responders” and therefore have to handle disasters for hours or even days before state and foreign resources arrive on the scene.
- *Preparedness* consists of planning how to respond in case an emergency or disaster occurs and working to increase the resources available to respond effectively. Preparedness covers contingency planning, resource management, mutual aid and

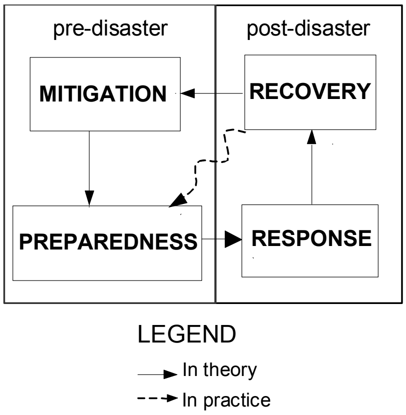
cooperative agreements with other jurisdictions and response agencies, public information, and the training of response personnel.

- *Recovery* constitutes the final phase of the disaster management cycle. Recovery continues until all systems return to normal or near normal. Long-term recovery from a disaster may go on for years until the entire disaster area is either completely restored or redeveloped for entirely new purposes that are less disaster-prone. Recovery activities encompass temporary housing, restoration of basic services (e.g. water, electricity), food and clothing, debris clearance, psychological counselling, job assistance, and loans to restart small businesses

In the past, this process was thought to be composed of four distinctive phases, but now there is increasing recognition that the phases can and should overlap considerably. Disaster responders, for example, should be taking measures to facilitate recovery, as well as encourage preparedness for the next disaster and mitigation to reduce its impact.

Figure 1.3: Disaster Management Phases

The theoretical conditions of disaster management. In practice, however, the cycle operates differently since mitigation is often overlooked. Mitigation measures should be two-fold: prevention of development in hazardous land and reduction of damage in built-up areas.



Waugh (2000) considers that disaster management should attempt to develop disaster *resistant*, *resilient* and *sustainable communities*.

- Disaster resistance is achieved through land-use regulations, building codes, engineering works and other mitigation programmes.
- Disaster resilience is achieved by developing the necessary medical facilities, social services, public education and other capabilities useful in disasters and crises.
- Sustainable communities are achieved by incorporating disaster management into their economic, environmental and social programmes.

One of the most serious problems threatening disaster management relates to planning authorities relying on raw information such as hazard zonations rather than on integrated information such as property damage and human casualty forecasts. Analysis of hazard mapping alone is not enough for the mitigation of disasters, as hazard mapping only depicts the natural phenomena. Tucker, Trumbull et al. (1994) clearly illustrate the problem by indicating that the 1988 Spitak earthquake in Armenia (former USSR) and the 1989 Loma Prieta earthquake in California were of similar size and affected populations of comparable size. However, the Armenian event killed 25,000 people whereas the Californian earthquake killed 63. The difference in the casualty figures lies in vulnerability levels. It is therefore necessary to move forward by analysing the impact that the natural phenomena could have on the urban “elements” (e.g. population, buildings, lifelines) as well as the multiplying effect that might be caused by the interaction between these “elements”.

The document entitled “Methodological Guide for the Formulation of Regional Urban Plans; Applicable to Cities” issued by the Colombian government is a clear example of how urban planning is carried out in many countries. The guidelines are very thorough in describing the procedure for deriving hazard maps for earthquakes, floods and landslides. They are also very thorough in showing how to map population densities, land-uses, infrastructural services (both social and physical), the socio-economic status of the population, and environmental issues such as ecological conservation, mining effects and pollution. However, a major gap can be observed in these guidelines since there is no mention of “what to do next”. The following is the only description given: “This hazard information is useful when contrasted to maps on population density, infrastructure location and socio-economic profile of the population” (IGAC 1996). But how can one compare or “contrast” them? As the document makes no reference to this issue, it is evident that, despite the acknowledgement of the importance of integrating multi-disciplinary information, there is a gap in terms of how to perform this.

Menoni, Petrini et al. (1997) consider that a comprehensive approach to assessing systemic vulnerability, especially when this term refers to urban and regional systems, has still to be fully developed. Similarly, Papadopoulos and Arvanitides (1996) report that in Greece several investigators have developed methods for assessing earthquake hazards, although “only a very limited number of papers related to the earthquake risk description have appeared”. These authors have indeed identified where a serious gap in knowledge lies.

In a seminar the Developing Member Countries (DMCs) of the Asian Development Bank (1991) concluded that the importance of risk and vulnerability analyses was recognised, even though they were not always widely practised. Delegates felt that such analyses should be mandatory in the appraisal of all future projects. Such appraisals would not be achieved without additional costs, but it was felt that the resulting benefits would by far exceed the cost involved.

Russel, Rahman et al. (1991), when describing the case of Nepal, gave a description that applies globally. They consider that cost-benefit analysis of disaster mitigation measures is not currently practiced. Comprehensive risk mapping and vulnerability analyses for the various sectors do not exist and no common reference norms are available. Decisions on where major government infrastructure or construction projects should be located tend to be taken subjectively.

1.2 PROBLEM STATEMENT

Two very important problems hampering the reduction of disaster losses in urban areas are hereby identified and constitute the main problems that the research will tackle:

- **The lack of economically and rapidly produced inputs for risk (damage) assessment, preventing the cost-benefit implications of disaster mitigation and prevention measures to be assessed.**
- **The lack of clarity related to the integration of risk assessments into the urban planning and management process.**

Using a geographical information system (GIS) to integrate and process data, the research will concentrate on the particular problem of forecasting direct urban disaster losses (of human life and buildings) attributable to earthquake hazards, for the purpose of improved urban planning and management. The research will focus on earthquake loss, and its ultimate objective is to help bridge a serious gap that exists between the mapping of hazardous events and urban decision-making and policy-making.

1.3 RESEARCH OBJECTIVES

The **main objectives** that the research aims to achieve are the following:

1. To develop a methodology for providing timely and economically feasible inputs for assessing the earthquake risk of people and buildings. This requires identifying what data should be collected and how. Different data collection methods will be analysed in terms of speed, effectiveness and cost. Since the aim is to develop a method that is applicable to urban areas where few data and economic resources are available, focus will be given to:
    - Developing a method for data collection that could be carried out mostly by non-specialists (e.g. undergraduates, construction workers, building inspectors) rather than the complex data acquisition techniques that only highly trained and costly specialists can perform.
    - Utilising video and photograph capture and interpretation for developing an inventory of relevant building and population characteristics.

2. To test such methods in a case study and evaluate the strengths and weaknesses of the methodology.

3. To establish how to effectively incorporate risk assessment into the process of urban strategy formulation, with particular emphasis on its contribution to establishing the cost-benefit of mitigation measures.

4. To evaluate the use of GIS as a tool for:
    - Data storage and integration interoperability
    - Zonation of urban risk
    - Urban decision-making

1.4 THE CHOICE OF A CASE STUDY

The city of Cartago in Costa Rica, a highly hazard-prone city, constitutes an interesting site for testing the developed methodology. It lies 1,200 m above sea level in what is known as Costa Rica's "Central Valley". Cartago is located downstream of rivers originating near the crater of the Irazú volcano and has been washed away by lahars (mudflows of volcanic origin) several times in the course of its history (see Figure 1.4). On the path of one of these rivers lies the San Blas landslide, considered the biggest landslide in Central America in terms of volume.

Two active seismic faults, located a few hundred metres from built-up areas, are responsible for earthquakes which devastated the city last in 1841 and 1910. This city therefore requires a disaster management plan that is not only appropriate but also of a multi-hazard nature, as a volcanic eruption can trigger a lahar or an earthquake can trigger a landslide.

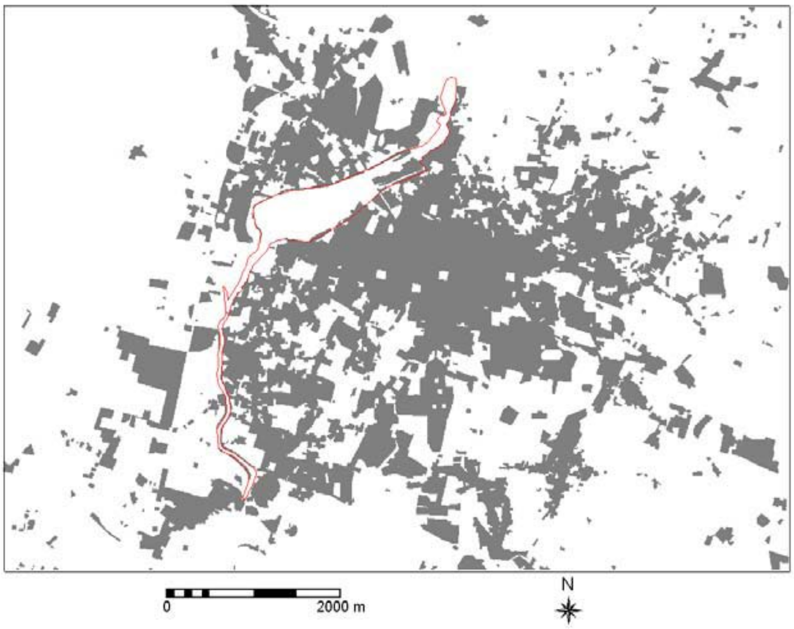


Figure 1.4: Schematic Map of the City of Cartago
(red line illustrates the boundary of the protective dyke)

Hazard mapping, digital cartography and socio-economic data are available. From the point of view of time for data handling and processing, the city is manageable, since its population is approximately 150,000 inhabitants. Other reasons in favour of this site are that the city is very diverse in terms of the building materials.

1.5 OUTLINE OF THE DISSERTATION

The dissertation is divided into nine chapters as presented in Figure 1.5.

The **first chapter** describes the thematic context of the study, the main problem to be addressed, the research objectives and the reasoning behind the selection of the case study. In terms of the thematic context, the effects of natural hazards in urban areas are documented. It addresses the need to produce forecasts of possible loss (of human life and property) attributable to the different hazardous events that could take place, and their use for establishing the cost-benefit of alternatives to ensure successful urban policies and adequate economic resource allocation.

In **Chapter Two**, a general literature review is presented. The chapter begins with a review of the calls made by the various international organisations dealing with disaster and urban growth issues on the subject of disaster mitigation planning. The second part of this chapter presents a sequence of questions that best describe what the decision-making process in hazard-prone urban areas should include. The opinions of different authors regarding the various issues are recorded and discussed. The need to establish disaster information networks (DINs) and the role that could be played by the World Wide Web (www) will be discussed.

Chapter Three explains physical parameters that can be associated with hazards in general. In terms of the types of hazards to be analysed and considering the time available, a decision was made to restrict the research to the assessment of damage due to earthquakes. The main characteristics of earthquakes are reviewed in order to explain the reasoning behind the components of risk assessment methodologies.

Chapter Four is devoted to reviewing current views and methodologies for population and building vulnerability and risk determination for earthquakes. The problems detected are highlighted. Concluding remarks include the reasoning behind the two areas of interest that will be explored in the research.

Chapter Five presents a description of the methodology that will be utilised, as well as a description of the required data inputs. The damage data to be used for testing the methodology in the case study will be described. This chapter discusses technological aspects such as aerial photo interpretation and video capture and processing, spatial data modelling and stratified sampling techniques.

In **Chapter Six,** Costa Rican urban planning and disaster management policy is analysed and various relevant regulations are discussed. The stakeholders are identified and both their roles and responsibilities are analysed.

In **Chapter Seven**, the case study is described. First, a geographical and historical description of the city of Cartago is given. Next, the particularities of the datasets in terms of their availability, resolution, currency and format are presented.

In **Chapter Eight,** the results of the risk assessment are analysed and the implications of these results for the formulation of urban strategies are elaborated.

In **Chapter Nine,** the conclusions of the research are presented as well as a number of recommendations for further research.

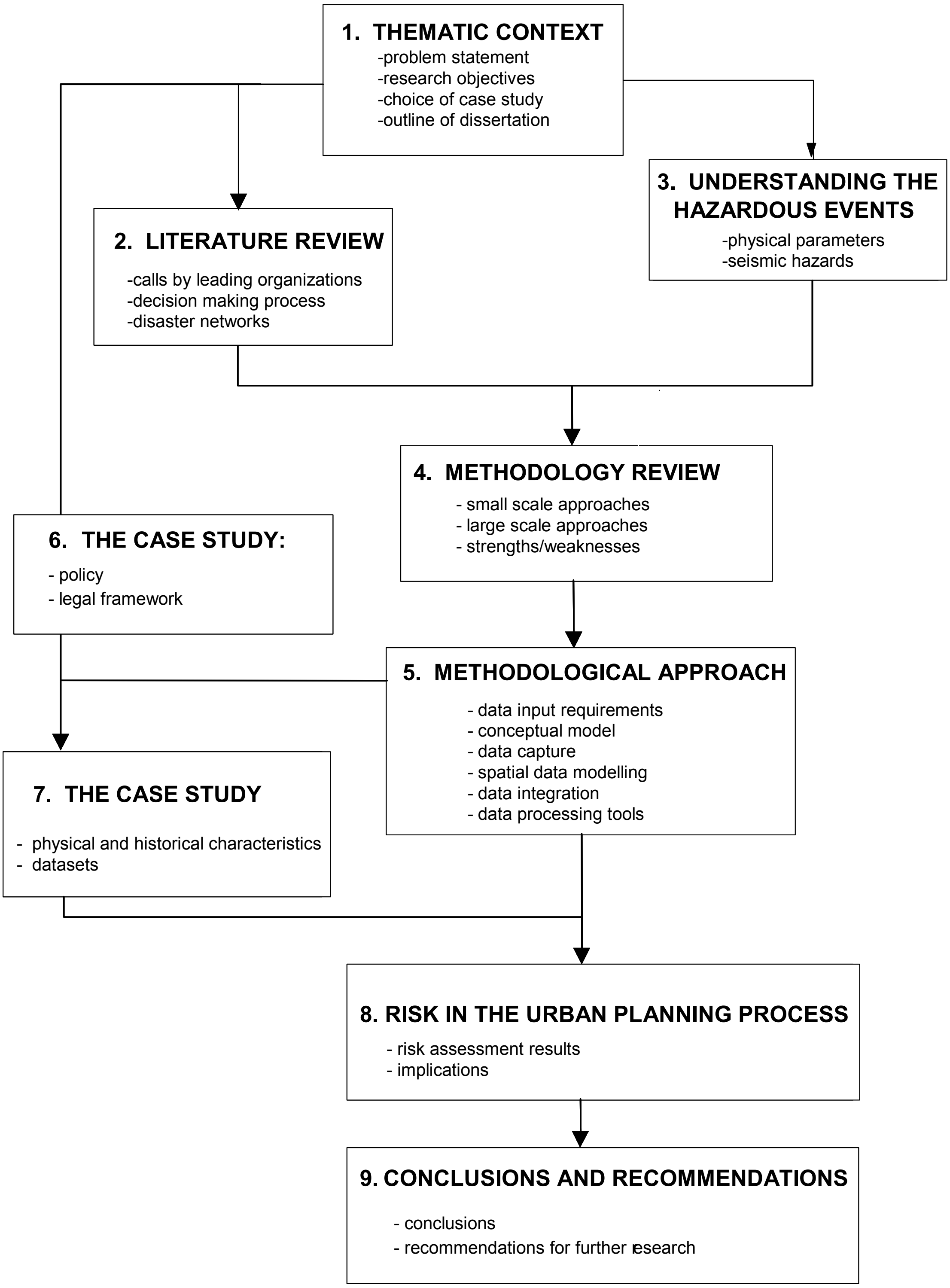


Figure 1.5: Flowchart of the Dissertation

Chapter Two: LITERATURE REVIEW

In this chapter the stance of institutions such as the United Nations on the topic of natural hazards will be discussed, as well as the programmes launched. A literature review will be presented related to the interdependency of issues surrounding disaster management, as well as the move towards disaster information networking via the World Wide Web. The last section in this chapter presents a summary of reasons why disaster management is a challenging and complex task. Chapter Three explains the physical parameters of hazards in general and discusses the characteristics of earthquakes and their implications for buildings.

2.1 SCOPE FOR IMPROVEMENT

The United Nations launched the International Decade for Disaster Reduction (IDNDR 1990-2000) with the objective of raising people's awareness of what they can do to make themselves safer from natural disasters.

In order to achieve this objective, the following goals were declared for the decade:

- To improve the capacity of each country to mitigate the effects of natural disasters, with special attention being given to assisting developing countries in assessing disaster damage potential, and in establishing early warning systems and disaster-resistant structures.
- To devise appropriate guidelines and strategies for applying existing scientific and technical knowledge, taking into account cultural and economic diversity.
- To foster scientific and engineering endeavour aimed at addressing critical gaps in knowledge in order to reduce loss of life and property.
- To disseminate new and existing technical information related to measures for assessing, predicting and mitigating natural disasters.
- To develop measures for assessing, predicting and mitigating natural disasters through programmes of technical assistance and technology transfer, demonstration projects, education and training, and to evaluate the effectiveness of those programmes.

In 1994 the member countries of the United Nations launched the Yokohama Strategy and Plan of Action for a Safer World, which provided the guidelines for disaster prevention, preparedness and mitigation. The Yokohama strategy emphasises the following issues:

- Human and institutional capacity-building and strengthening
- Compilation and sharing of information via networking
- Risk assessment as well as the monitoring and communication of forecasts
- Sub-regional, regional and international cooperation

- Mobilisation of resources

Parallel to the United Nation’s initiatives and in the context of the American continent, the Organisation of American States (OAS, 1991) has made a call for its member states to:

- Incorporate natural hazard considerations early in the process of integrated development planning and investment project formulation
- Put a higher value on risk reduction in evaluating investment projects
- Increase the proportion of expenditure for prevention activities relating to rehabilitation, relocation and reconstruction

Unfortunately, not all organisations show a consistency between their manifestos and the activities that they carry out and the topics for which they make funding available. For example, during an interview a senior officer with the OAS Natural Hazards Project pointed out that this office, in the belief that such information would not be used, did not fund projects related to the development of methods for deriving forecasts of human loss and building damage at urban level. The decision was based on the belief that most politicians are only concerned with macro-economic figures, such as forecasts of possible loss of agricultural or industrial production through natural events.

This somewhat contradictory behaviour is in part to be blamed for “the critical gaps in knowledge” that the United Nations mentioned as one of the key issues that need to be tackled. It also helps one to understand the reason for the paradox between the advances in science and the slow reduction in the rate of losses caused by natural hazards.

2.2 THE THINKING PROCESS IN HAZARD-PRONE URBAN AREAS

To some extent, the task of urban planners relates to gathering, processing and presenting data to allow a series of questions to be answered so that decision-makers can formulate successful strategies.

The first question in this sequence is: ***what is the risk?*** – in other words, what would be the expected losses in human life, property and production if the scenario or scenarios presented by earth and atmospheric scientists took place?

2.2.1 Deriving Risk

To explain how risk is assessed, the following United Nations definitions (1991) are provided and a summary is made regarding the disciplines concerned:

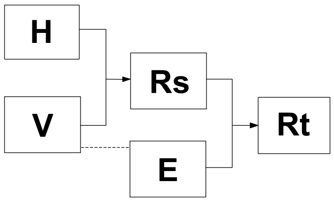


Figure 2.1: Conceptual Flowchart of Risk Assessment

Natural hazard (H) determination involves the estimation of the probability of occurrence (within a specific period of time in a given area) of a potentially damaging natural phenomenon. The disciplines concerned are earth and atmospheric science.

Vulnerability (V) determination involves the estimation of the degree of loss suffered by a given element at risk or a set of such elements, resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage). The disciplines concerned are human geography, construction engineering, etc.

The elements at risk (E) include the population, buildings, civil engineering works, economic activities, public services, utilities and infrastructure, etc., at risk in a given area.

Specific risk (Rs) determination involves the estimation of the expected degree of loss due to a particular natural phenomenon and as a function of both natural hazard and vulnerability ($Rs=H\cdot V$). The disciplines concerned are human geography, construction engineering, etc.

Risk (Rt) determination involves the estimation of the expected damage or loss of property and human lives and the disruption of economic activity due to a particular natural phenomenon ($Rt=E\cdot Rs$). The disciplines concerned are urban planning, urban and human geography, and economy.

The flowchart in Figure 2.1 illustrates the methodology for vulnerability and risk determination leading to economic loss estimation.

When such risk has been determined, planners need to decide whether ***it is within tolerable limits.***

2.2.2 Acceptable Risk

Risk may be at “acceptable levels”, not requiring or necessarily justifying government intervention, or it may be “unacceptable”, requiring small to massive investments to mitigate the threat to life and property. Petak and Atkinsson (1982) view it in terms of the size of the gap between the desired state of affairs and perceived reality (see Figure 2.3). In their view the size of this gap determines whether some action must take place. Whenever this gap is small, little or no intervention is necessary. Their view highlights the importance of empirical work in creating an adequate model of the "real world". In the case of disaster management, this translates into models to estimate the losses of a human, physical and economic nature. Failure to model this "real world" will therefore hamper the decision-making process.

Cardona (1997) considers "acceptable risk" to be the possible losses that could be accepted by a community in return for a degree of profit or benefit. The United Nations Disaster Relief Co-ordinator (1984) considers it unacceptable when "a community undergoes severe damage and incurs such losses to its members and physical appurtenances that the social structure is disrupted and the fulfilment of all or some of the essential functions of the society is prevented".

Waugh (2000) considers that the notion of "acceptable risk" is an acknowledgement that it is not possible to eliminate completely all risk from hazards. Establishing where to draw the line, however, is a very difficult task since acceptability is related to social values, the state of knowledge about the hazard, the credibility of the warning, and perceptions about the exposure. Those who choose to live in Mexico City, with its well-known seismic hazards, assume some risk. Some people may not fully understand the risk and once they have experienced a major earthquake may pack and move to a more stable area, while others may simply adjust to living with the hazard. The determination of "acceptable" levels also may be controversial because different individuals and different communities may well have different notions of how much risk they are willing to accept. Younger people may take more risks than older people. Property owners may be less willing to ignore hazards than renters and other more transient populations. Business owners and managers, too, may be less inclined to take actions to reduce risk when the actions may result in significant financial losses.

How to define what is acceptable and adjust public policy accordingly is both a methodological and a political problem. Risk-taking behaviours by individuals and communities can increase the level of risk for others. While there is little debate concerning the need to rescue individuals, there is increasing debate concerning their responsibility for the cost of the rescue operations and their liability for deaths and injuries to search and rescue personnel (Waugh 2000). As a consequence, some governments require disaster victims to pay for rescue operations when they have knowingly put themselves at risk.

According to the same author, in public policy terms, the level of threat posed by a particular hazard should determine its priority vis-à-vis other threats and problems. With finite resources, communities, like individuals, have to choose when and where to invest their money and their energy (see Figure 2.3).

Some people have tried to establish what is “acceptable risk” or “risk tolerance” in a quantitative form. Sheehan and Hewitt (1969) consider acceptable an event that has consequences below the following values:

- 100 people dead or
- 100 people injured or
- US$ 1 million in damage

The obvious weakness of this approach is that it is based on a threshold rather than on a ratio, and it is therefore totally subjective.

The Centre for Research on the Epidemiology of Disasters (CRED) (in Smith 1996) at the University of Louvain, Belgium, uses the following criteria for establishing which events are “disastrous”:

- 100 people dead
- 1% of the total national population in affected people
- 1% of the total annual GNP in damage

The ratio criteria for damage and affected people indicate more accurately the impacts of a disaster on countries with small populations and weak economies and constitute a better way of measuring risk.

Starr (in Cardona 1997), for example, after having surveyed different communities, has suggested that acceptable population risk is that which is below 1 death per 1 million people exposed. However, all these numbers are subject to debate since what is “acceptable” varies from culture to culture. Others such as Wiggins et al. (also in Cardona 1997) consider that the ratio should be 0.1 rather than 1.

When the risk is not acceptable, urban planners are faced with the need to know **how risk can be reduced.**

2.2.3 Risk Prevention and Reduction

Alexander (1993) highlights a very important issue as he points out that, broadly speaking, there are two ways of dealing with risk mitigation:

- Risk aversion involves a decision to achieve the maximum possible risk mitigation, regardless of the costs involved. This method does not allow one risk to be compared with another in order to apportion scarce resources; neither does it allow the balancing of costs and benefits. This method has been widely used in disaster management with very negative results and it is now considered only applicable to certain advanced technologies such as air travel, nuclear hazards and to virulent diseases.

- Risk balancing helps determine what risks are acceptable and thus helps set goals for community mortality, morbidity and economic loss. This approach assumes that some positive level of risk is socially acceptable.

Broadly speaking, risk can be reduced by adequate disaster management. Choosing the right implementation strategy, however, can be difficult since there are many available options. Figure 1.3 in Chapter One gives an insight into the points in time when strategies could be implemented. This can be further expanded by means of a tri-dimensional matrix (see Figure 2.2) describing the range of possible implementation measures, including levels of government (who will implement the strategy?), management phase (when will the strategy be implemented?) and implementation measure (how will it be implemented?).

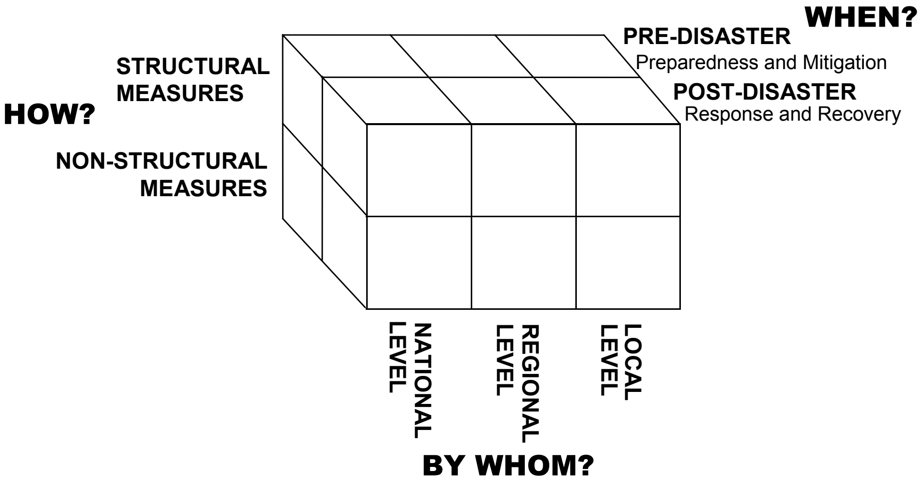


Figure 2.2: Range of Implementation Strategies (Masser and Montoya 2000)

The combination of these elements defines the range of possible implementation strategies. In practice, some blocks are more common than others, although all are possible. Examples of these strategies include, to name just three:

- A national emergency commission (national level) implementing an educational campaign related to the evacuation of buildings (non-structural measure) to lower the vulnerability of people to future earthquakes (pre-disaster measure).
- A municipality (local level) building a dyke (structural measure) in order to lower the vulnerability of the population and buildings to future floods (pre-disaster measure).
- A ministry of public works (national level) repairing a bridge (structural measure) destroyed by a flash flood (post-disaster measure).

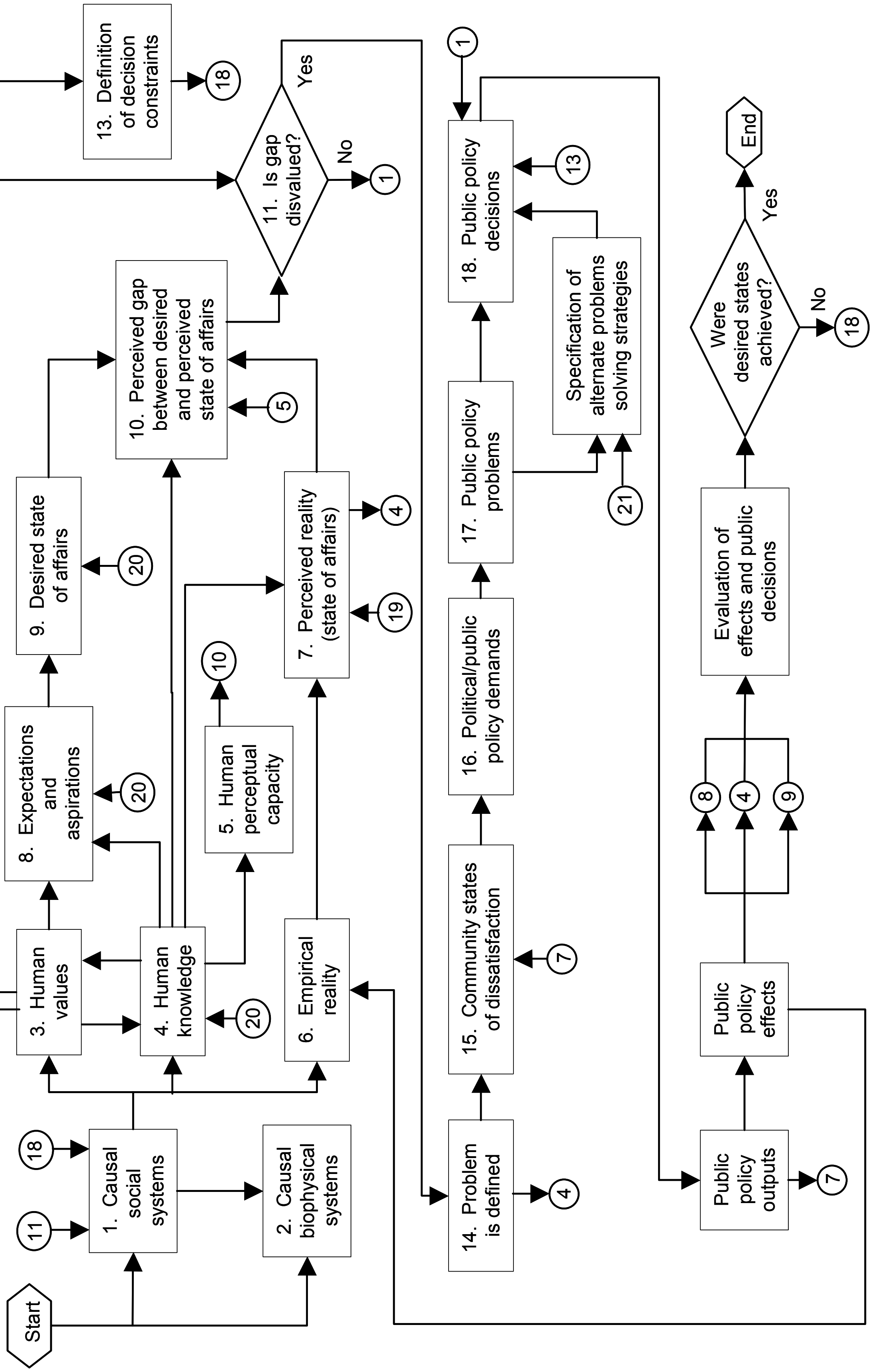


Figure 2.3: Decision-Making Process (Petak and Atkinsson 1982)

There are many implementation measures for risk mitigation that must be carefully analysed. They can be broadly classified into structural and non-structural measures. Non-structural measures involve urban development restrictions as well as educational campaigns, while structural measures involve the modification of the environment. According to the United Nations Disaster Relief Co-ordinator (1991), the following are several of the possible measures:

- To modify the hazard by means of:
    a. Protective measures that aim to reduce the impact of the hazard. Such measures include constructing dykes or dredging river basins. The protection of sites is often a costly option, and should therefore be related to capital investments in the area as a whole and compared carefully with other options.
    b. Site improvement that mitigates the disaster by changing the physical characteristics of the site itself. The objective of this option is to prevent the triggering of the hazard (i.e. landslides) or to regulate its impact by ground improvements or drainage and slope modification.

- To reduce structural vulnerability by improved engineering design, by construction methods and by strengthening. Strengthening construction, however, does not contribute to risk reduction when the vulnerability is 100%. This is the case for most landslides and for the direct effects of volcanic eruptions.
    a. Strengthening of buildings: resistance can be increased by means of waterproofing or strengthening against ground shaking.
    b. Strengthening of infrastructure: the physical strength of infrastructure systems is improved in order to ensure adequate functioning of day-to-day facilities and services during and after a natural disaster. Infrastructure systems require high public investments; it is therefore important that the vulnerability of such elements be low.

- Changing the functional characteristics of settlements, such as changing the population density, the layout of a neighbourhood or the relative importance of infrastructure systems.
    a. Regulation of land-use: in this option, risks are reduced not by reducing the hazard-proneness of the site, but by changing the functional characteristics of the hazard area. An important problem in the regulation of land-use is enforcing the plans. Regulation may be problematic, especially within existing settlements. Relocation of settlements is an option, although it can have far-reaching negative consequences.
    b. Expansion or duplication of infrastructure: the impact of natural hazards on the functioning of infrastructure systems is reduced by increasing the number of connections, or loops, within the system. Although expansion of infrastructure may require high public investment, such infrastructure investments may stimulate economic development.

Apart from the issues raised by the United Nations, the following elements are also important:

- Education campaigns to raise the awareness of hazards and risks as well as of warning and evacuation systems.
- Modification of the loss burden by stimulating the insurance sector to offer disaster insurance (and reinsurance) and by creating disaster funds within the communities themselves.

Smith (1996) considers that one of the major problems is that systematic research into natural hazards began recently with people such as Gilbert White (White 1936; White 1945), who was the first in the USA to recognise that structural measures were not the only way to tackle floods. Structural measures include – to take floods as an example – the construction of dykes to provide protection against river or sea floods. In Vietnam, people have been building and maintaining such structures for some 2000 years (Benson 1998). According to Wu (in Smith 1996), some five million Chinese lost their lives in floods between 1860 and 1960, despite the fact that the flood "engineering" defence of cities dates back over 4,000 years.

One very important aspect to be reviewed relates to law enforcement, as sometimes the single issue of enforcing existing building and other development regulations would considerably decrease the probability of damage. Monzón-Despang and Gandara-Barorit (1994) clearly highlight this issue by pointing out that in Guatemala City, the municipality is only capable of monitoring 40% of the formal construction due to lack of personnel and a high level of clandestine construction. According to the Independent Insurance Agents of America (2000), losses from Hurricane Andrew could have been reduced by as much as 30 to 40% had existing building codes been properly enforced. Kunreuther (in Waugh 2000), for example, supports a system that includes monetary incentives to reduce risk, fines for non-compliance, tax credits to encourage mitigation programmes, well-enforced building codes and effective land-use regulations.

In establishing possible non-structural measures such as educational campaigns, another question must be answered: what or who do people blame for disasters?

2.2.4 Risk Perception

As Smith (1996) pointed out, one of the biggest challenges is to resolve the resulting conflict between technical risk analysis and the more subjective risk perception. The degree of perceived risk varies greatly between individuals of the same age and sex, depending upon education, location, occupation and lifestyle. It also varies from country to country as a consequence of educational campaigns. For example, according to Kaneko (1994), in the

Japanese prefecture of Saitama, 65% of the population is aware of the threat of a major earthquake, while Ventura and Schuster (1994) consider that in the Greater Vancouver Regional District only 50% of the population is aware of the seismic risk. Unfortunately, it is not only a question of modifying the perception of risk as, due to income, many people accept voluntary risk and engage in a constant game of “Russian roulette” in return for some benefits. Twigg (1998) considers that in the Indian city of Indore the reasons why many slums are found on the banks or floodplains of several rivers are mainly:

- Proximity of the dwellings to the market
- Proximity to job opportunities
- Affordability of land
- Better chance of getting funds for improvement because of the slum’s visibility

On the other hand, when disasters are perceived as “Acts of God" and a specific religion is strongly observed, the task of vulnerability reduction is very difficult. According to Haque (1997), in 1985 about 34% of the floodplain occupants in Bangladesh (27% in 1995) perceived the occurrences of erosion events as the “will of Allah”. His research shows that the perception of the causes of erosion relates to educational attainment. The educated part of the population (with relatively better accessibility to the media and other sources of technical knowledge) demonstrated better perception of the causes of hazards. About 38% of respondents with “no education” stated that erosion was the “will of Allah” while only 17% with secondary and post-secondary education expressed the same view. Similarly, his study proved that the relatively higher-income groups are more aware of these hazards than the marginal ones. Haque goes further by analysing the displaced people’s perception. He found that 32% of them with less than three relocations perceive the cause to be the “will of Allah”, while 45% of displaced people with more than 12 relocations share this fatalistic view.

Festinger’s theory of cognitive dissonance – or as Tobin and Montz (1997) refer to it: “denial” behaviour – helps to explain why this reaction exists. His theory suggests that individuals reject information and suppress facts that might be damaging to their prevailing value system. Fortunately, this way of thinking is on the change in most countries. For example, in the USA, Smith (1996) believes that the classic defence of “Act of God” in cases of civil liability for human and property losses through landslides carries decreasing credibility, and recent court judgements have tended to identify the developer, or his consultants, as mainly responsible for damage due to failure.

The media also play an important role in the public perception of disasters. According to Hawkins (1993), aircraft accidents deter some potential passengers from flying, while the daily carnage on the roads seems to have no equivalent effect. The reason, he believes, lies mainly in media coverage of air accidents.

Urban planning is a very complex discipline in which a series of objectives must be achieved. To name but a few, these include the provision of education, medical, infrastructural and recreational services to the community; employment opportunities for all; and the encouragement of economic development. In the light of the scarce economic resources that developing countries possess, the cost of structural measures to prevent or mitigate disasters must be carefully investigated through cost-benefit analyses.

This implies the need to address a third question: from amongst the people themselves, the government, the insurance industry and local or foreign donors, ***who will pay for the losses?***

2.2.5 Financial Victims

Disaster insurance plays a vital role in urban economy. Where this is not available, it is entirely up to the people themselves and government agencies (themselves or through foreign aid) to pay the costs of reconstruction and relief. Adequate insurance coverage therefore allows the losses to be shared amongst a broader group, thereby reducing the financial burden on the government and/or the people involved. Kunreuther (in Waugh 2000) considers that an insurance system with rates based on risk can serve as the cornerstone of a disaster management programme. Kunreuther (1998) considers that insurance has the advantage over all other policies in that through lower premiums it rewards individuals prior to a disaster for investing in loss reduction measures, as well as paying these same people for damage suffered through a disaster. They consider that, for insurance to be effective in both these roles, those who are at risk must bear a substantial portion of the costs of residing in hazard-prone areas, otherwise they will have limited economic incentive to take protective actions and will rely on others to bail them out later after the next disaster.

According to Waugh (2000), reliance upon private insurance raises some serious questions. First, can the private insurance industry provide enough coverage to ensure that substantial proportions of property losses are covered after a major disaster? With some qualification, the answer to this question is yes; but there may be serious problems in areas in which a single disaster or series of disasters can overwhelm the capacities of insurance providers. Insurance companies depend upon the existence of a large pool of customers (the “law of large numbers”) who share the risk but do not all experience losses at the same time.

In 1994, the insurance industry of California collected US$ 500 million in earthquake premiums but paid out US$ 11.4 billion in damage caused by the Northridge disaster (Valery 1995). According to Smith (1996), as a consequence of the large insurance claims following hurricanes Hugo (1989), Iniki (1992) and Andrew (1992), plus the Northridge (1994) earthquake, several companies in the USA were forced out of business. More precisely, and according to Kunreuther (1998), losses through Hurricane Andrew alone triggered the failure of nine small and medium insurers, which were caught off guard by the very large increases in exposure in hazard-prone areas and inaccurate loss estimates. Similarly, the National Insurance Institute (INS) in Costa Rica (a government-owned monopoly company) would have probably been unable to cover the losses due to the 1990 earthquake if the government had not bailed it out.

Faced with the prospect of losses that cannot be forecast, the insurance industry either over-charges, limits its liability in various ways or fails to offer disaster coverage. It becomes evident that the less certainty in terms of possible losses, the more reluctant insurance companies are to offer disaster insurance. In the UK, the policy-holder base has been deliberately widened by including storms and floods as part of the “standard comprehensive household structure and contents policy”. In Japan, on the other hand, special earthquake clauses have been introduced to limit indemnity to a maximum of US$ 110,000, of which the government might have to pay a portion. Waugh (2000) considers that, in anticipation of catastrophic events, insurers may raise rates high enough to cover the “probably maximum loss”, require a deductible so that property owners share the risk, and/or buy reinsurance to cover losses in excess of expectations. While private insurers theoretically can raise rates high enough to cover almost any losses, the cost may be prohibitive for all but the most affluent property owners, and even they may choose to accept the risk rather than pay for the insurance.

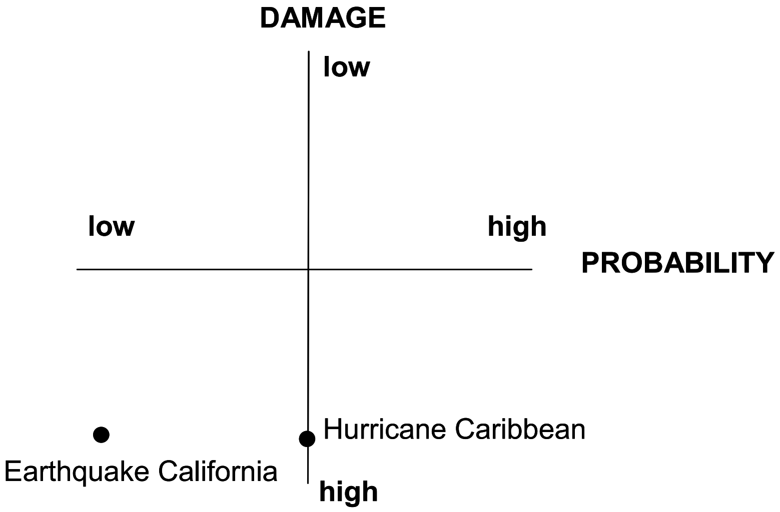


Figure 2.4: Perception of Damage and Probability (comparison between earthquake perception in California and hurricane perception in the Caribbean)

Unfortunately, the vast majority of the property at high risk from earthquakes is currently uninsured, even in countries where governments support insurance schemes or where they hold a monopoly over insurance. Most policies are on commercial and industrial property rather than on residential property. It is very common that the only residential property to be insured is that which is tied to a mortgage, as insurance is most often a requirement for the granting of loans. According to Smith (1996), in 1995 only 3% of homeowners in Kobe had earthquake insurance. Broadly speaking and according to the Insurance Information

Network of California (1999), traditionally about 25 to 30% of Californian homeowners carry earthquake insurance. In the San Fernando (California) earthquake of 1971, property damage amounted to some US$ 500 million, of which only US$ 32 million were covered by insurance (Hudson and Petak 1981). Since the subsequent disaster loan programme provided over US$ 257 million in aid, it is evident that the general tax-payer assumed much of the financial burden (Smith 1996). This relates directly to the problem of awareness and perception, as an individual living in a hazard-prone area may view an earthquake as a low probability / high consequence event. This is in contrast to the situation in Jamaica, where a major factor in the recovery after Hurricane Gilbert (1988) was the relatively high level of insured risk – approaching 40% (Kunreuther 1998) – due to the perception of hurricanes as medium probability / high consequence events (see Figure 2.4).

It is important to realise that high insurance coverage does not necessarily ensure the re-establishment of activities following a disaster. In most cases, insurance premiums are set on the basis of property valuation, and unfortunately many property owners undervalue their property to reduce property tax and insurance premiums. The post-disaster payout by the insurance company will be a fraction of the market value and therefore many property owners will be unable to rebuild to pre-disaster levels unless they possess savings or some funding is made available. Moreover, elderly or middle-aged business owners may simply choose to take their insurance payments and retire rather than invest the time, effort and money necessary to rebuild to pre-disaster levels. Therefore, despite high insurance coverage, disasters can have devastating effects on the economic base of a community.

A careful balance must be sought, as the availability of both foreign and national disaster aid may discourage municipal governments as well as individual home and business owners from adequately insuring their property and adopting other mitigating measures. Roth et al. (in Bolt 1994) consider that the greatest overall benefit from earthquake insurance accrues when there is a link between the availability of low-cost insurance and a requirement to upgrade the seismic resistance of the structure. In the case of homes, inspections at the time of purchase should establish premium levels according to the degree of risk inherent in the dwelling and its location. An important side benefit could be the widespread reduction of risk, not by government regulation but by market incentives contained in graduated insurance premiums.

Disaster aid results from humanitarian concern following the loss of life, and as such it is applauded on moral grounds. Foreign disaster aid, however, can never fully rectify the economic and social disparities around the world that are responsible for so much vulnerability. Foreign aid is not ideal as a long-term measure for disaster reduction, as it is dependent upon the state of the national and foreign economies as well as upon diplomatic relations.

Despite the efforts to organise disaster relief, the results are often disappointing. After Hurricane Mitch hit Central America (1998), the national emergency commissions in the affected countries called on foreign countries to stop the collection of clothing as they considered the true need to be food and drinking water. This highlights the problems of useless disaster aid. Similarly, following the Guatemala City earthquake (1976), the peak in the delivery of medical supplies happened after most casualties had already been treated and hospitals were back to normal levels (Smith 1996). According to the same author, the field hospitals supplied to Guatemala by neighbouring countries were the only fully effective ones and, by the time the main supply of "packaged" disaster hospitals arrived from the USA, a surplus of hospital beds was available in the capital city. Brown et al. (in Tucker, Trumbull et al. 1994) go even further in their criticism of the effectiveness of national foreign disaster agencies in meeting the needs of developing countries. For example, they consider that the technical assistance provided by the USA has not served to foster an independent science and technology capability of the most needy developing nations. They argue that US development philosophy focuses on supplying technology and expertise to developing nations rather than on contributing to indigenous capability. Further, they point out that this aid has been targeted at just a few countries and the research agenda usually reflects the priorities of the "donor" rather than those of the host nation.

Following the earthquake in Managua, Nicaragua (1972), allegations were made regarding the corruption of high local officials in the distribution of foreign aid. This created a situation in which a donor agency from Mexico refused to allow its goods to be unloaded from its plane (by then already at Managua airport) until permission was granted for distributing the aid directly to the affected people. The cargo returned to Mexico as such permission was never granted. This illustrates some of the many difficulties and weaknesses surrounding foreign disaster aid. These examples highlight two criteria that are of immense importance in dealing with disaster aid and resources in general:

- Efficiency refers to the adequate allocation of economic resources to maximise social welfare
- Equity relates to fairness in the distribution of resources

2.2.6 Cost-Benefit Analysis

If the risk is not within "tolerable limits", ***what are the costs of the various prevention and mitigation measures?*** Cost-benefit analyses are a necessity in establishing the feasibility of prevention and reduction measures. Cost-benefit analysis was developed by the Navigation Boards in the USA in the 1920s. In 1936, in light of the ever-increasing costs of flood alleviation, cost-benefit analysis was incorporated in the Flood Control Act, which specified that "the benefits, to whomsoever they accrue, must justify the costs" (Sewell et al. in Tobin and Montz 1997). Similarly, Dixon (in Tobin and Montz 1997) demonstrated the value of cost-benefit analysis graphically, showing that the size of a project and availability of funding might influence project selection (as shown in Figure 2.5). Different project goals have different benefit-cost ratios. For example, maximising the benefit-cost ratio (B) yields a different result than maximising net benefits (C). Erdik (1994) considers that certain simple measures that have essentially zero cost compared with the benefits deserve to be implemented immediately. A few examples of this include evacuation drills and the tying-down and securing of furniture, appliances and electronics in homes and offices.

Because risk-modified cost-benefit analysis has not been integrated into the project activities of most development agencies, it is not possible to fully judge its potential effectiveness. Kramer (1994), for example, considers that national and international development agencies often act as if their programmes and natural disasters are unrelated. Risk analysis constitutes a prerequisite since without the knowledge of the possible losses the benefits of mitigation measures cannot be established. Efforts, therefore, to produce risk zonations must be high on the urban agenda. The Organisation of American States (OAS) (1991) considers that the forecasting of losses should be a concern not only for the countries in which they occur but also for international lending agencies and the private sector, as they should be interested in protecting their loans and investments. A few examples from Benson (1998) that help describe the impact of risk-modified cost-benefit analysis are given below:

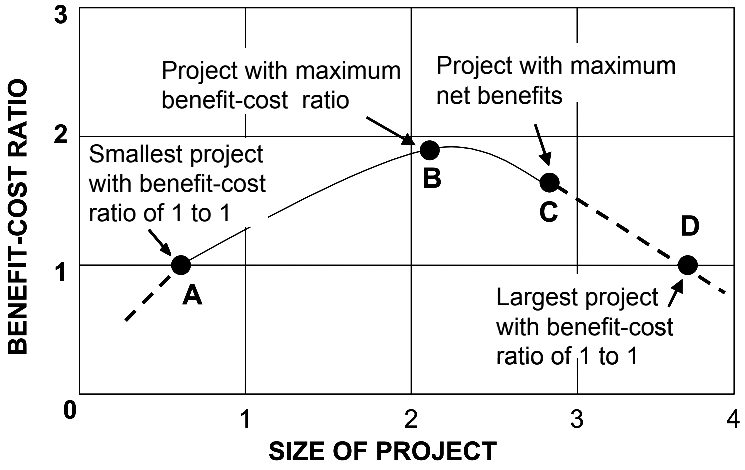


Figure 2.5: Benefit-Cost Ratios (source: Tobin and Montz 1997)

- The World Bank and USA Geological Survey calculated that economic losses worldwide from natural disasters in the 1990s could be reduced by US$ 280 billion if US$ 40 billion were invested in preparedness, reduction and prevention strategies.
- In China, US$ 3.15 billion have been invested over the past 40 years in measures to control floods; this is believed to have averted potential losses of US$ 12 billion.
- The Thames Barrier project to protect London from floods cost £ 730 million sterling, but this was considered a wise investment because the potential loss of property through a Thames flood was £ 3.5 billion (the flood was considered inevitable even though it might not have taken place for many years).

- The Anheuser-Busch company spent US$ 30 million on preparations to protect its brewery in the San Fernando Valley in California against earthquakes. These included plans for alternative water supplies. When an earthquake hit the area, the company saved more than US$ 300 million because these measures enabled it to carry on production with only minimal interruption.
- The owner of a sweetshop in India, interviewed in 1994, said he had paid 25 rupees to put stepping stones around his shop so that customers would not have to stand in flood water. Not to have done so would, he reckoned, have cost him 100 to 200 rupees in lost business.

However, cost-benefit analysis in disaster management is not as simple as the previous examples have depicted. Since it also involves preventing the loss of lives, establishing the benefit of each saved lived is a fraught issue. To many, equating human life with a financial value appears both illogical and morally questionable. Failing to do so, however, implies that decisions regarding mitigation strategies are based solely on property and production. Where life-saving is to be evaluated in financial terms, the most widely used method is the "human capital approach", in which a life is valued in accordance with its potential for future productivity. The monetary value of an individual's life is the sum of all of his or her expected future earnings. Unfortunately, distinguishing between the value of different individual's lives on the basis of their earning power is liable to lead to unacceptable decisions; for example, it could be computed that there was a zero or even negative loss in the collapse of an old people's home, (as the inhabitants may not be receiving either a salary or pension, and the state may be keeping them). Similarly, the lives of people living on low incomes would be assigned a lower value (United Nations Department of Humanitarian Affairs 1994). In the case of reinforcing of weak structures, one of the difficulties in the analysis relates to the trade-off between life safety and construction costs. According to Bolt (1994), this trade-off is well illustrated by recent studies of the seismic resistance of state-owned buildings in California. It is estimated that over US$ 20 billion-worth of state property is involved, and much of it is vulnerable to damage. The California Seismic Safety Commission, after testing the proposed hazard evaluation methodology on 40 state-owned buildings, recommended that priorities for upgrading these structures should be based on a benefit-cost ratio (BCR), defined as the number of lives saved per reconstruction dollar. As a consequence, structural engineers were retained to provide a prioritised list of state-owned structures based on the BCR method. Such a list was essential to obtain cost estimates so that the state government could fund a realistic schedule of upgrading.

In summary, to ensure successful urban disaster management, three different types of information must be made available to decision-makers (see Figure 2.6):

- "Financial resilience" (self-coping) capacity, which refers to the degree to which the different owner groups can cover the economic losses either themselves or through disaster insurance.

- Disaster assessment of likely hazardous events for economic losses (i.e. property damage) and human casualties, and the triggering effects of natural phenomena.
- Cost of mitigation measures.

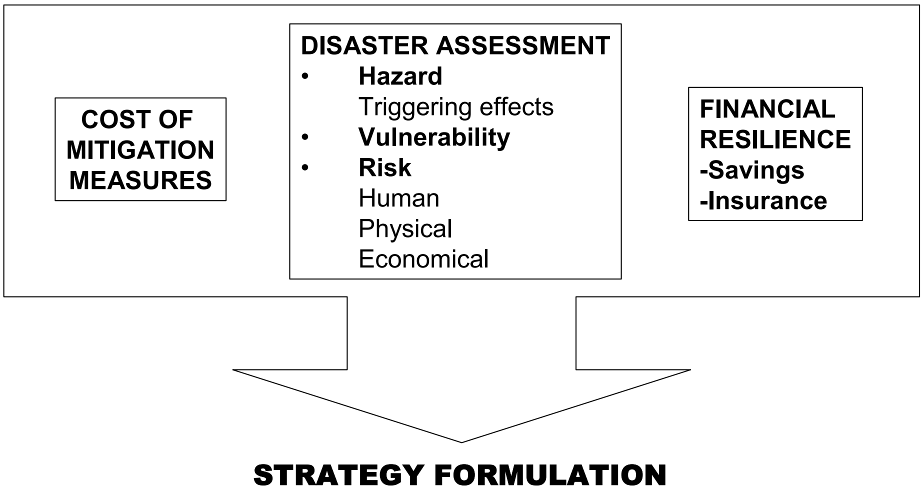


Figure 2.6: Three Crucial Information Sets for Strategy Formulation in Hazard-Prone Urban Areas

Risk assessment involves a fragile chain. Siccardi and Adom (1993) point out the three reasons why the chain can fail:

- Failure of scientists to correctly forecast: meaning their inability to locate the harmful event in space and time and to measure the uncertainties involved.
- Failure of scientists to predict, formulate a message and correctly transfer the full information with their uncertainties.
- Failure of the human community to perceive the complexity of the message, which results in the inability to take suitable action.

2.3 THE NEED FOR NETWORKS IN URBAN DISASTER MANAGEMENT

Accurate information presented in a timely and appropriate manner to facilitate informed decisions is of high importance in ensuring that these decisions lead to success. Failing to acknowledge that disasters do not respect boundaries is a first step in preventing different government organisations from wasting valuable time and resources by producing virtually duplicated information.

It is observed that a common error in developing countries is related to the belief that government organisations (with the help of universities or consulting firms) should collect information and process it with the intention of using it for decision-making at only the government level. It is therefore important to identify all the potential users of risk zonation information within the public and private sector and to establish the positive role they could play in the economic sustainability of the data produced by government agencies. The insurance industry, for example, should be seen not only as a user of governmentally produced data but also as a provider of valuable information, since insurance coverage is an important parameter for urban disaster planning. Bertz (1994) emphasises the importance of establishing close cooperation between the insurance industry and disaster management agencies, while Kunreuther (1998) believes that only through joint efforts with other stakeholders can insurers overcome their problems.

On the other hand, substantial information already exists that could be used to this end, but there are numerous obstacles to accessing it and the necessary methods for integrating it from a variety of sources for use in decision-making are presently inadequate.

Implementation of an improved national or international network for making better information available in a more timely manner could substantially improve the situation (Commission on Geo-Science Environment & Resources of the US National Research Council 1999).

It is therefore important to expand from the concept of a single user / single data provider to the concept of multiple users and multiple data providers. The selling of data is crucial to achieving the necessary economic sustainability of data production for all the information providers. However, computer linking via the internet provides the perfect tool for enabling access and transfer of the required data amongst the stakeholders.

As the above report points out, another problem present even in a highly developed nation such as the USA relates to the lack of uniformity in the availability of information across the country. Information is often produced from disparate sources and transmitted in whatever format the provider prefers, requiring significant effort to compile it in a form that provides a coherent picture or even thwarting integration altogether. Data standards are often inconsistent and, even more dangerous, users are sometimes unaware of the limitations and uncertainties in data or are presented with conflicting interpretations of data without the means to assess the reliability of the sources. Along with the technical difficulties in accessing information and assessing data reliability, impediments arise from the lack of interaction between users and providers of information. No entity exists to coordinate or foster communication amongst these groups.

The first and key step in achieving this objective is to involve all the stakeholders by:

- Identifying potential users and their data needs (see Figure 2.7), since disaster information users' needs vary considerably.
- Identifying potential data providers as well as the characteristics of the data they could provide (type, resolution, reliability and currency of the data).
- Identifying an entity that will coordinate or foster communication amongst these groups.

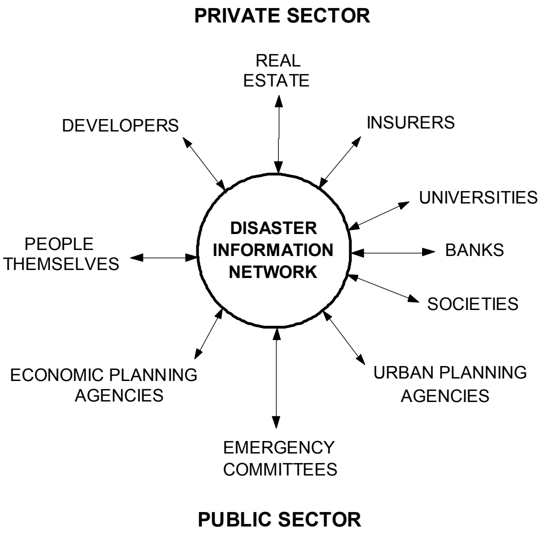


Figure2.7: Members of a Disaster Information Network

There are already initiatives related to the design of networks such as the National Disaster Information Network (NDIN) in the USA (Federal Emergency Management Agency 1997). The objective of the NDIN is first to set up a disaster information network within the USA and later to link it to similar networks in other countries.

Work already carried out as part of the NDIN initiative included conducting a survey to identify user needs. The survey is a key step in identifying commonalties in terms of data needs amongst the different institutions. One important aspect, however, would be to survey not only the ideal data needed but also the “minimum acceptable data”. The reason is that a compromise is likely to be required between the quality of the data and the speed and cost of data acquisition since, even with the private sector’s willingness to purchase loss prediction information, the necessary predictions might still be economically unfeasible.

According to the Commission on Geo-Science Environment & Resources of the US National Research Council (1999), the overall goal of a disaster information network should be to reduce the rate of disaster losses. Some of the features it should include are:

- Improved methods for finding information with specific attributes, for example for a particular area or type of hazard.
- Ways to determine the source, quality and reliability of information, including standards for data compatibility.
- Systems or software for integrating information rapidly to produce and deliver information tailored to the needs of a decision-maker for the specific problem at hand
- Courses to train users and build awareness.

The focus of a DIN should be on developing integrative products for decision-makers. Top priority should be accorded to this area because the wealth of information that resides in numerous databases cannot be readily utilised by those who must take action to reduce risks or respond to disaster losses. A few examples (from the many that could be cited) of integrative products are:

- Local maps showing how hazards and risks vary in space and time.
- Estimates of probability of occurrence of hazardous events.
- Estimates and examples of potential effects, especially on structures.
- Real-time display of what is happening during the course of a disaster.
- Systems for contingency planning.
- Codes, standards and construction methods for structures.

2.4 COMPLEXITY OF URBAN DISASTER MANAGEMENT

Waugh (2000) considers that disaster management programmes are difficult to design, implement and coordinate for the following reasons:

- Disaster management is a low-priority political issue, only getting on the public agenda during or immediately after a disaster. Officials and the public are also quick to forget the lessons learned from disasters and thus are fated to repeat mistakes.
- Disaster management programmes generally do not have strong political constituencies to support effective action and to encourage larger budget allocations. Residents seldom lobby for stronger building codes and more restrictive land-use regulations or vote for funding mitigation measures.
- Regulatory efforts to reduce the impact of disasters and to manage known hazards better often meet strong opposition. Without data to substantiate the need for regulatory programmes, with the benefits expressed in dollar terms, there is little to offset the economic costs of regulation.
- Disaster management programmes generally do not have politically influential administrative constituencies. Key personnel are often political appointees and may not remain in office long enough to implement effective counter-disaster programmes. Relatively few elected officials and career public administrators understand and appreciate the importance of disaster management programmes. Disaster managers are often out of the administrative mainstream, in small and ill-funded offices. They may be viewed as lacking recognised technical expertise and administrative skill, and/or the level of education of other officials.
- The effectiveness of emergency management policies and programmes is difficult to measure unless there has been a disaster.
- The technical complexity of disaster management programmes frequently makes them difficult to explain to the public and to officials who control budgets, as well as making it difficult to design effective programmes.

- The horizontal and vertical fragmentation of the government creates jurisdictional confusion and leads to coordination problems.
- It is often difficult to create good working relationships amongst national, provincial and local agencies because fiscal, administrative and policy-making capacities differ greatly.
- The current political climate is more hospitable to programmes that are decentralised and is also more supportive of state and local self-reliance, particularly in fiscal matters.
- Financial resources for new programmes and initiatives are scarce at any level, unless it can be documented that they will save money or a "policy window" created by a major disaster stimulates public support for action.
- The diversity of hazards complicates the assessment of risk and the design of disaster management programmes.

2.5 CONCLUSIONS

It was concluded that urban disaster management is a complex issue as it involves multiple stakeholders and strategy possibilities which can be implemented at different points in time. Moreover, disasters are often regarded as "Acts of God" and therefore the issue of human perception must be always taken into account. It was also concluded that as disasters do not respect political or administrative boundaries, the establishment of information networks should be high on planning agendas. Finally, since disaster management is only one of many issues that decision-makers face, efforts must be made to raise awareness of the benefits of disaster mitigation.

Chapter Three: DESCRIBING THE EARTHQUAKE PHENOMENON

Rather than focusing on the production of hazard zonations and vulnerability determination, this research focuses on developing a methodology for the production of an inventory of buildings, the data integration necessary to estimate risk, and the use of these estimations for the purpose of urban strategy formulation. It is necessary, however, to review the most important characteristics of natural phenomena as this allows a better explanation of the reasoning behind the various risk assessment methodologies that have been developed. Particular attention is paid to those earthquake characteristics that have a strong bearing on structural damage. Chapter Four reviews the approaches to earthquake damage assessment by different groups and presents a summary of the strengths and problems detected.

3.1 PHYSICAL PARAMETERS OF NATURAL HAZARDS

In describing hazard zonation maps, it is necessary to explain concepts related to the physical parameters of natural phenomena. Tobin and Montz (1997) consider the following to be the relevant parameters of natural events:

- **Physical mechanisms** relate to magnitude, duration and spatial distribution of natural hazards. By measuring *magnitude*, one can define the knowledge of nature and improve the response. The magnitude of natural hazards represents a force of nature rather than determining the vulnerability of a particular population. It is important to distinguish between magnitude and intensity. Magnitude should be considered as an appraisal of the physical parameter of a geophysical event (i.e. the Richter Scale for earthquakes), while intensity relates to the impact of an event on human systems. Sometimes assessments of some hazards are given as intensity estimates since direct measurements are difficult to make. Two examples of intensity scales are the Fujica Scale for tornadoes and the Modified Mercalli Intensity Scale (MMI) for earthquakes (refer to Appendix 1). The *duration* scale for natural events ranges from a few seconds (as in the case of earthquakes and tornadoes) to years (as in the case of droughts). The *spatial distribution* relates to the area in which the hazardous events take place. In most cases, natural phenomena can be spatially defined and therefore mapped.

- **Temporal distribution** refers to frequency, seasonality and diurnal patterns. By examining the *frequency* (also known as return, recurrence and occurrence period or interval) of specific hazardous events, it is possible to establish whether particular physical processes can be delineated within a temporal framework, such as on seasonal or diurnal scales. The traditional approach for measuring an event’s return period has been to analyse historical records by calculating the average number of occurrences over a specific time period. It is important to note that return periods can be misleading since there are periods of high activity followed by periods of low activity that are overlooked.

Over a million earthquakes are detected by sensitive seismographs on Earth every year. From the analysis of such records, one can conclude that small earthquakes occur more frequently than larger ones. However, over 50,000 of these earthquakes are large enough to be felt by people each year (Table 3.1).

Descriptor	**Magnitude**	**Average Annually**
Great	8 and higher	1
Major	7 - 7.9	18
Strong	6 - 6.9	120
Moderate	5 - 5.9	800
Light	4 - 4.9	6,200 (estimated)
Minor	3 - 3.9	49,000 (estimated)
Very Minor	< 3.0	Magnitude 2 - 3: about 1,000 per day Magnitude 1 - 2: about 8,000 per day

Table 3.1: Frequency of Occurrence of Earthquakes Based on Observations since 1900 (USGS 2002).

Another temporal feature is *seasonality*, since some natural events occur more frequently at certain times of the year than others (i.e. hurricanes along the Caribbean take place between April and November each year). Diurnal patterns are observed only in the case of thunderstorms, which typically occur during the late afternoon.

- **Warning period** is also referred to as rapidity of commencement or speed of onset. This characteristic has a bearing on the success or failure of preventative action. Earthquakes, tornadoes and flash floods allow minimal to no warning. A longer warning period is possible for volcanic activity, tsunamis, hurricanes, floods, etc.

- **Triggering effects** relate to the secondary events that can take place following one main event (see Figure 3.1). For example, the eruption of the Colombian volcano Nevado del Ruiz in 1985 triggered a lahar (volcanic debris flow) that killed 23,000 people in the town of Armero. Epidemics claimed the lives of further inhabitants of Armero and were triggered by standing water and decomposing human and animal bodies. Awareness of triggering effects is a very important issue and unfortunately one that is frequently overlooked by disaster managers.

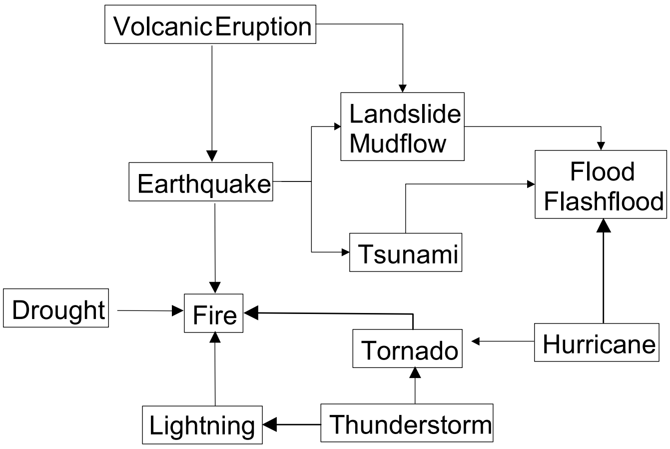


Figure 3.1: Triggering Effects by Various Natural Phenomena

3.2 SEISMIC HAZARD

An earthquake is the vibration of the Earth's surface caused by the release of energy in the Earth's crust. The sudden dislocation of segments of the crust usually generates this energy, although it can also be caused by man-made explosions or volcanic eruptions. The most destructive earthquakes are of a tectonic nature, caused by the sudden dislocation of large rock masses along geological faults within the Earth's crust.

The remaining sections in this chapter are largely based on US Geological Survey literature (USGS, 1997), and are presented to explain terminology that is used in Chapter 4.

3.2.1 Faults and Seismic Waves

A fault is a fracture within some particular rocky mass within the Earth's crust. Some faults can be many hundreds of miles long. Fault length is one important parameter, depth another. The sudden movement of the two sides of an active fault, where both sides of the fracture move with respect to each other, causes an earthquake. This topic constitutes the field of global tectonics, which studies the deformation of the Earth’s crust.

Over the course of time, the two sides of an active fault move slowly but continuously in relation to each other. This movement is known as fault slip and it may be as little as a few inches or so per year. The movement of these two sides of the fault with respect to each other cannot be entirely smooth. The motion along the fault is accompanied by the gradual build-up of elastic strain energy within the rock. The rock stores this strain like a giant spring being slowly tightened. Eventually, the strain along the fault exceeds the capacity of the rocks (at that point) to store any additional strain. The fault then ruptures, which means that it suddenly moves a comparatively large distance in a comparatively short amount of time.

The time it takes for a particular area to reach the limit of elastic strain varies greatly. Compared with the typical human life span, however, it is usually long, varying anywhere from a few decades to a few thousand years. The average time it takes for earthquakes of a given magnitude to re-occur along a fault is known as the recurrence interval for that fault.

Most importantly, the rupture of the fault also results in the sudden release of the strain energy that has been built up over the years, resulting in seismic waves**.** These waves travel outward from the source of the earthquake along the surface and through the Earth at varying speeds, depending on the material through which they move. It is actually the seismic waves caused by the sudden release of energy as a fault suddenly slips that creates most of the destructive effects.

3.2.2 Earthquake-Related Hazards

As Shedlock and Tanner (1999) point out, earthquake hazard assessment attempts to answer three basic questions:

- Where do earthquakes occur?
- How often do earthquakes occur?
- How big can we expect these earthquakes to be?

Earthquake-related hazards can be roughly divided into ground motion and collateral damage (refer to Figure 3.2). This dissertation will focus on the effects of ground motion only.

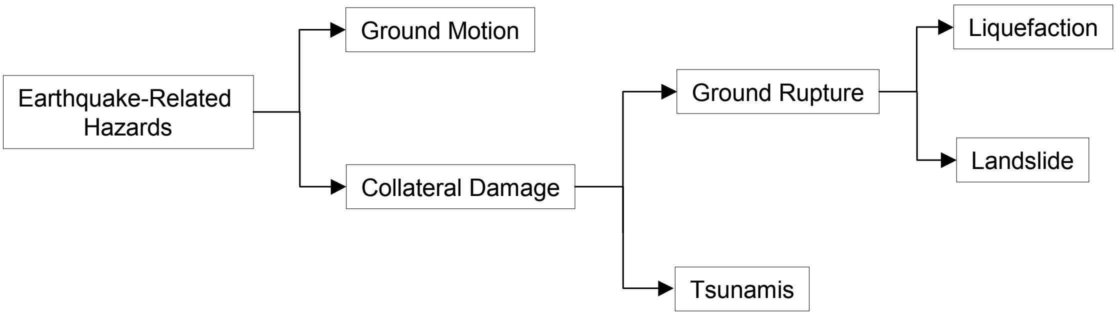


Figure 3.2: Classification of Earthquake-Related Natural Hazards

Ground Motion

When seismic waves reach the surface of the Earth at such places, they give rise to what is known as “ground motion”. The most destructive of all earthquake hazards is caused by seismic waves reaching the ground surface at places where human-built structures, such as buildings and bridges, are located.

Strong ground motion causes buildings and other structures to move and shake in a variety of complex ways. Many buildings cannot withstand this movement and suffer damage of various kinds and degrees. Most casualties, damage and economic losses caused by earthquakes result from strong ground motion acting upon buildings incapable of withstanding such motion. It is for this reason that it is often said, "Earthquakes don't kill people, buildings do." Earthquake shaking can cause buildings and bridges to collapse; disrupt gas, electricity and telephone services; and sometimes trigger landslides, avalanches, mudflows, flash floods, fires and tsunamis (huge destructive ocean waves).

Collateral Damage

Ground rupture consists of liquefaction and landslides. Liquefaction takes place when loosely packed, water-clogged sediments at or near the ground surface lose their strength in response to strong ground shaking. When soil loses its bearing strength, buildings and other structures that rest on it will settle. As observed following the 1985 Mexico City earthquake, structures may remain intact but become tilted. In this case, the structure will probably need to be rebuilt, but little loss of life results.

Landslides, another type of ground failure, are often highly destructive. Davidson (1997) considers that, besides damaging buildings and other structures, landslides can increase the impact of an earthquake by blocking and destabilising roads, and by inducing flash floods through blocking rivers. Like liquefaction, landslide hazard is discussed in terms of susceptibility, opportunity and potential. Susceptibility depends on soil cohesion, water level and slope steepness. Opportunity depends on ground shaking demand, precipitation, and distance to the earthquake source. During the 1964 Anchorage (Alaska) earthquake, landslides triggered by very strong local ground motion devastated the Turnagain Heights residential development and many downtown areas in Anchorage. According to the United Nations Disaster Relief Co-ordinator (1991), in the 1970 earthquake in Peru, which claimed 70,000 lives, about 20,000 people perished in the avalanche of debris from the north peak of Nevado Huascarán.

Another important class of earthquake hazards are tsunamis. According to Smith (1996), these result from the tectonic displacement of the seabed associated with large, shallow-focus earthquakes under the oceans, but they can also be caused by exploding volcanic islands and large rock-falls into confined bays. Tsunami is a Japanese word meaning “huge wave”, although in reality it consists of not one but a series of waves. The crests of the waves may not extend far above the level of the water, but they may extend far below. The wavelength (distance between wave crests) may stretch for a hundred or more kilometres, making the tsunami difficult to detect until it is in shallow water. As the wave approaches the seashore, it increases in height due to the pulling of water from the shore. The first warning that a tsunami is about to hit is usually the receding water. The run-up is the maximum height the wave reaches and the inundation is the maximum distance it travels once it reaches shore. Because there may be considerable time between waves – even though they can travel 800 km an hour – people have been killed returning to their homes after the initial waves. In 1952 an earthquake off the coast of Kamchatka Peninsula, Russia, caused a Pacific-wide tsunami that caused extensive damage in Hawaii. Similarly, in 1960 Hawaii was hit by a major tsunami that originated off the coast of Chile in South America. While there was considerable property damage in Hawaii and California, the devastation was greatest in Chile, where 330 to 2000 were killed (Waugh 2000). The Risk Management Systems Corporation Inc. (RMS) (in Davidson 1997) considers that three factors determine the severity of a tsunami:

- The seismic source mechanism (i.e. magnitude and type of earthquake faulting mechanism)
- The distance and seafloor topography over which the tsunami travels as it propagates from the source to the destination
- The topography of the coast at the run-up site

Damage to buildings also causes a variety of secondary effects that can be greatly destructive. Fires, for example, are often created as a result of building damage resulting from an earthquake. These post-earthquake fires have on some occasions in the past reached catastrophic dimensions. The great San Francisco earthquake of 1906 and the Kanto (Japan) earthquake of 1923 were followed by fires that were amongst the largest peacetime fires in human history. Fires that break out following earthquakes can be very destructive since there might be simultaneous ignitions and, moreover, the fire suppression capability may be impaired by damaged water supply systems, the unavailability of personnel, and restricted mobility due to debris-filled and damaged roads. Davidson (1997) considers that three main components govern the fire hazard:

- The number and location of potential ignition sources (i.e. gas-line breaks, overturned water heaters, electrical shorts, flammable liquid spills)
- The ease with which fire will spread in the city due to the distribution of fuel (i.e. wooden structures, building contents)
- The ease with which fire can be controlled due to the characteristics of the region’s fire suppression agencies (i.e. management, fire-fighting personnel, emergency water supply, equipment)

3.2.3 Magnitude and Intensity of Earthquakes

The severity of an earthquake can be expressed in terms of both *magnitude and intensity*. Despite the two terms bearing different meanings, they are often incorrectly used as synonyms.

The area of the fault where the sudden rupture takes place is called the *focus* or *hypocentre* of the earthquake. The point on the Earth's surface directly above the focus is called the *epicentre*. The magnitude is related to the amount of seismic energy released at the hypocentre. It is based on the amplitude of the earthquake waves recorded on instruments that have a common calibration but are located at various positions. Seismographs record a trace that shows the varying amplitude over time of ground oscillations beneath the instrument. Sensitive seismographs, which greatly magnify these ground motions, can detect strong earthquakes from sources anywhere in the world. The time, location and magnitude of an earthquake can be determined from the data recorded by a number of seismograph stations. The magnitude is thus represented by a single, instrumentally determined value (the Richter Scale).

The Richter Scale is not used to express damage. An earthquake in a densely populated area which results in many deaths and considerable damage may have the same magnitude as a shock in a remote area that does nothing more than frighten the wildlife. Humans may not even feel large-magnitude earthquakes that occur beneath the oceans. According to Sauter (1989), each whole number step in the magnitude scale corresponds to the release of about 32 times more energy than the amount associated with the preceding whole number value. The local magnitude is determined using the $M = \log a/T + B$ relationship[1]. It can also be determined by using the nomogram presented in Figure 3.3. Given the epicentral distance (left axis) and the maximum wave amplitude A (right axis), a straight line drawn between the two axes determines magnitude M.

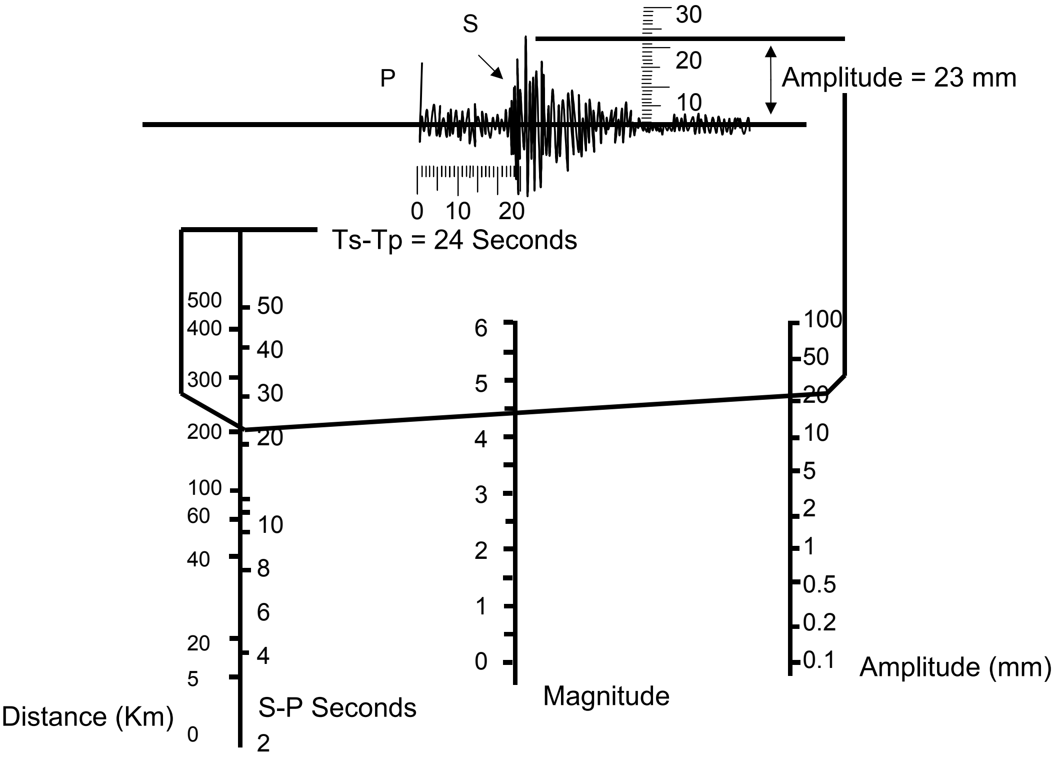


Figure 3.3: Determination of Richter Magnitude by Means of Nomogram (Bolt 1978)

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[1] Where *a* is the terrain displacement measured in microns (10 to -6 m), which is obtained by dividing the maximum amplitude of the record (*A*) by the amplification of the instrument; *T* is the wave's period in seconds and *B* is a factor that considers the epicentral distance and the attenuation of the waves.

The effect of an earthquake on the Earth's surface is called the intensity. Intensity is based on the observed effects of ground shaking on people, buildings and natural features. It varies from place to place within the disturbed region, depending on the location of the observer with respect to the earthquake epicentre and the local site conditions. The intensity scale consists of a series of certain key responses, such as people awakening, movement of furniture, damage to chimneys and finally total destruction. Although numerous intensity scales have been developed over the last several hundred years to evaluate the effects of earthquakes, the one currently used in many countries is the MMI Scale (refer to Appendix 1). The scale comprises 12 increasing levels of intensity, ranging from imperceptible shaking to catastrophic destruction, which are designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects. The lower numbers of the intensity scale generally deal with the manner in which the earthquake is felt by people. The higher numbers of the scale are based on observed structural damage. Structural engineers usually contribute information for assigning intensity values of VIII or above. It is important to note that many authors, amongst them Sauter (1989), consider that intensities between I and IV are irrelevant for seismic risk analysis as 90% of damage occurs from scale VIII upwards. Other intensity scales include Rossi-Forel, Medredev-Sponheuer-Karnik (MSK) and the European Macroseismic Scale 1998 (EMS).

The EMS Scale (refer to Appendix 2) also has a 12-degree range and is roughly equivalent to the MMI Scale. The major difference is in the detail. The different terms used are defined at the outset, in particular building types, damage grades and quantities, and these are now considered individually. Also, it is the only scale to be illustrated. Drawings show graphically precisely what is meant by the different damage grades and photographs can be used in the field for comparison with actual cases of damaged structures. Since the description of damage is more detailed, this scale is more useful for formulating damage reduction strategies and for prioritising work.

The intensity value assigned to a specific site after an earthquake is more meaningful to the non-scientist than the magnitude because intensity refers to the effects actually experienced at a particular place. To assign intensity values, for example, following a widely-felt earthquake, the US Geological Survey mails questionnaires to postmasters in the disturbed area, requesting information. The results of this postal survey and information furnished by other sources are used to assign an intensity value, and to compile isoseismal maps that show the extent of various levels of intensity within the felt area. The maximum observed intensity generally occurs near the epicentre.

3.2.4 Earthquake Prediction

Scientific understanding of earthquakes is of vital importance. The goal of earthquake research is to increase the reliability of earthquake probability estimates. Ultimately, scientists would like to be able to specify a high probability for a specific earthquake on a particular fault within a particular year. Earthquake prediction provides warning of potentially damaging earthquakes early enough to allow an appropriate response to the disaster, thus enabling people to minimise loss of life and property.

Scientists estimate earthquake probabilities in two ways: by studying the history of large earthquakes in a specific area and by measuring the rate at which strain accumulates in the rock. They study the past frequency of large earthquakes in order to determine the future likelihood of similar large shocks. For example, if experts estimate a 90% chance of a peak (maximum) ground acceleration (PGA) value of 0.10 g being exceeded at least once every 50 years, a return period of 22 years is implied (refer to the equations below). Stated in a different way, there is a 4.5% probability that such a scenario will occur in a year.

$$(1 - p)^n = 1 - P_n$$

$$R_p = 1/p$$

Where :

P_n = Probability that the value is exceeded in n years
R_p = Return period
p = Probability that the value is exceeded in one year

According to Shedlock and Tanner (1999), earthquake hazard can be estimated by means of a characterisation of the seismic sources, the attenuation of ground motion and the actual calculation of probabilities. Seismic catalogues are the main tool used to determine the seismic sources (where, how often and how big earthquakes are likely to be). These catalogues contain the following data:

- Date of occurrence
- Coordinates of the epicentre in degrees of latitude and longitude
- Focal depth
- Magnitude

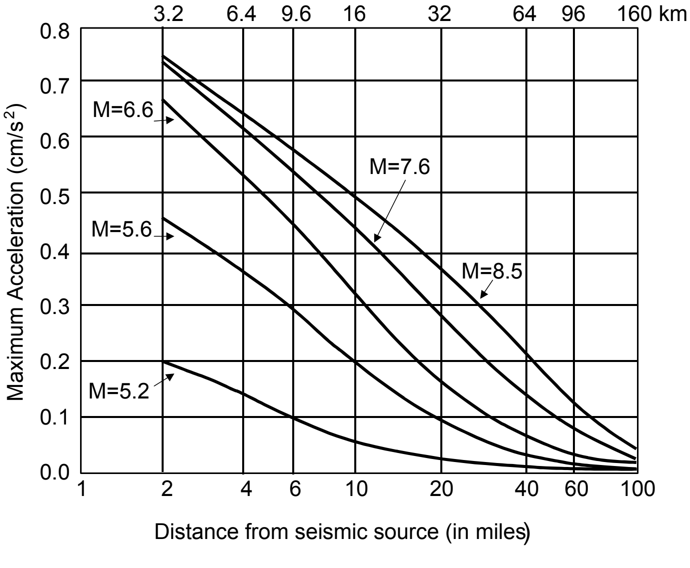

Figure 3.4: Attenuation Curves (Sauter 1989)

The most frequently used parameter to define ground motion is the PGA, expressed either as gals (cm/s^2) or as a percentage of gravity (% g). Attenuation relationships express the maximum acceleration produced by an event at a given site at a certain distance from the epicentre. In other words, they express ground motion as a function of magnitude and distance (refer to Figure 3.4).

A considerable amount of data regarding earthquakes is given in intensity (usually in MMI). Several researchers (the most widely known being Gutenberg and Richter (1942), as well as Trifunac and Brady (1975)) have therefore related PGA values, which are instrumental measurements, to the observed intensity values, which are subjective measurements. Figure 3.5 illustrates the relationships according to several authors; a considerable variance is observed and it highlights one of the many sources of uncertainty in risk assessment.

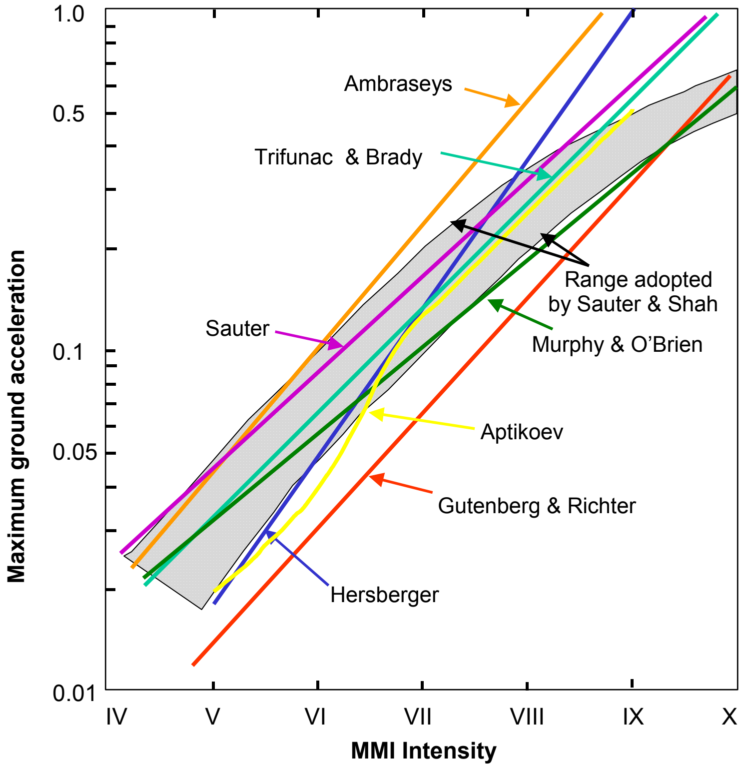

Figure 3.5: PGA – Intensity Relationships (Sauter and Shah 1978)

Gutenberg and Richter developed an empirical relationship between magnitude and occurrence (log N = a – b·M) to determine return periods[2] (refer to Figure 3.6).

The validity of the probability (and return period) results obviously depends on the amount and quality of data. Scientific information about earthquakes is very scarce and instrumental

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[2] Where *N* is the number of events of higher than magnitude *M* per unit of time; *a* and *b* are seismic fixed values characteristic of each zone; *M* is the magnitude expressed on the Richter Scale.

records have only been available for the past 100 years. The extrapolation into the future and the prediction based on data collected in such a relatively short period of time therefore make the predictions somewhat unreliable.

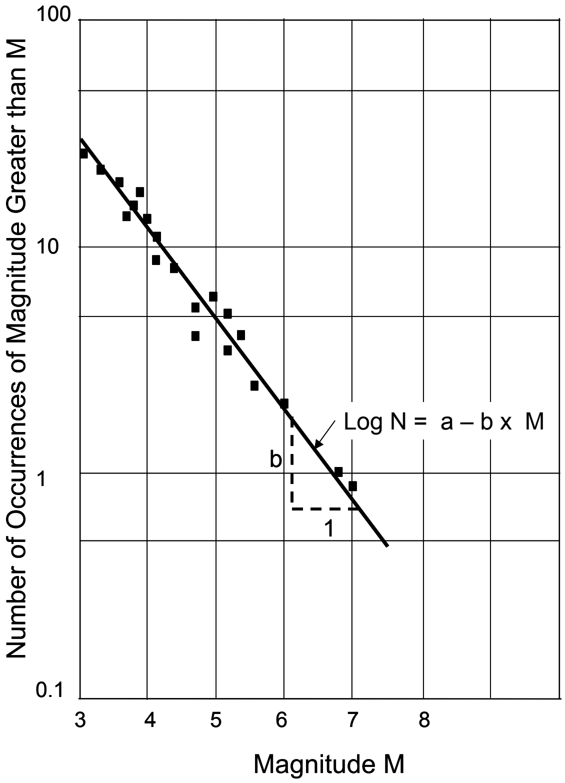

Figure 3.6: Gutenberg and Richter Relationship (Sauter 1989)

Another way to estimate the likelihood of future earthquakes is to study how fast strain accumulates. When plate movements build up the strain in rocks to a critical level, rocks will suddenly break and slip to a new position. Scientists measure how much strain accumulates along a fault segment each year, the time since the last earthquake along the segment, and how much strain was released in the last earthquake. This information is then used to calculate the time required for the accumulation of strain to build up to the level that results in an earthquake. This simple model is complicated by the fact that such detailed information about faults is rare. According to USGS (1997), in the USA only the San Andreas Fault system in California has adequate records for using this prediction method.

Both these methods, and a wide array of monitoring techniques, are being tested along part of the San Andreas Fault. Over the past 150 years, earthquakes of approximately magnitude 6 have occurred on average once every 22 years on this fault near Parkfield, California (the last one took place in 1966). Due to the consistency and similarity of these earthquakes, scientists have started an experiment to "capture" the next Parkfield earthquake. A dense web of monitoring instruments, including global positioning systems (GPS), was deployed in the region during the late 1980s. The main goals of the ongoing

Parkfield Earthquake Prediction Experiment are to record the geophysical signals before and after the expected earthquake, to issue a short-term prediction, and to develop effective methods of communication between earthquake scientists and community officials responsible for disaster response and mitigation. This project has already made important contributions to both earth science and public policy.

3.2.5 Ground Motion

The dynamic response of a building to earthquake ground motion is the most important cause of earthquake-induced damage. Failure of the ground and soil beneath buildings is also a major cause of damage. However, contrary to popular belief, buildings are rarely, if ever, damaged because of fault displacement beneath a building.

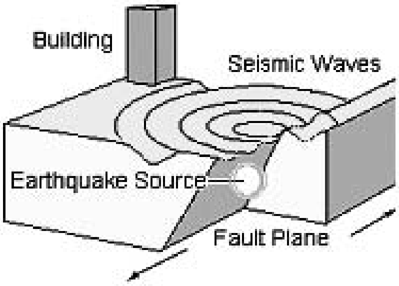

Figure 3.7: Ground Motion (USGS 1997)

The seismic waves travel for great distances before finally losing most of their energy (see Figure 3.7). At some time after their generation, these seismic waves will reach the Earth's surface and set it in motion, which not surprisingly is referred to as earthquake ground motion. When this phenomenon occurs beneath a building and when it is strong enough, it sets the building in motion, starting with the building's foundation. It then transfers the motion throughout the rest of the building in a very complex way, in turn inducing forces that can produce damage.

The complexity of earthquake-induced ground motion is due to three factors:

- Source effects: the seismic waves generated at the time of the earthquake fault movement are not all of a uniform character.
- Path effects: as these waves pass through the Earth on their way from the fault to the building site, the soil and rock media through which they pass modify them. When the waves pass through a material of different density, their speed and heading change (see Figure 3.8).
- Local site effects: once the seismic waves reach the building site they undergo further modifications, which are dependent upon the characteristics of the ground and soil beneath the building and the topography of the terrain.

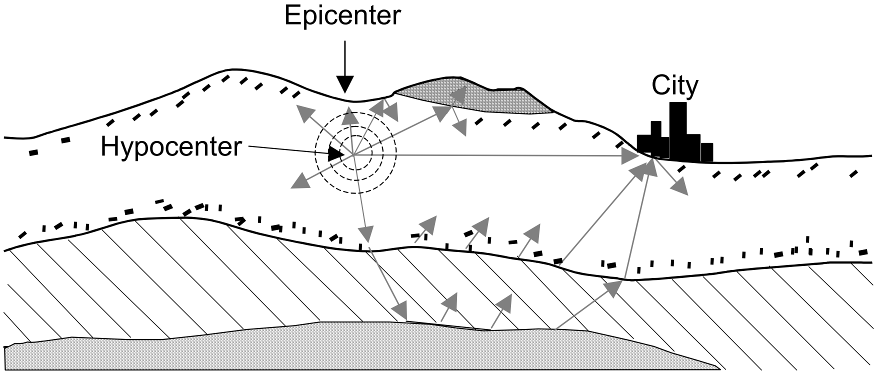

Figure 3.8: Path Effects of Seismic Waves (adapted from Bolt 1978)

The parameters of earthquake ground motions that have the greatest importance for buildings are: the duration, amplitude (of displacement, velocity and most importantly acceleration) and frequency of the ground motion. Frequency is defined as the number of complete cycles of vibration made by the wave per second. A complete vibration is the distance between one crest of the wave and the next, in other words one full wavelength (abbreviated as 1 Hz). Surface ground motion at the building site is a complex superposition of vibrations of different frequencies. At any given site, some frequencies usually predominate.

3.2.6 Site Effects

Earthquake intensity at a given site is attenuated or increased by local site conditions. Two significant factors that determine amplification are soil and topography. Urban (2002) considers that site conditions are perhaps the most complex subject to model within the field of earthquake hazard.

Soil Effects

According to the same author, the physical-mechanical properties of soil (i.e. cohesion, structure and depth of the superficial layers) influence the vertical transmission of the wave. In general, the intensity of ground motion is higher in unconsolidated soft soils than in firm soil or rock.

According to Finn (1994), damage patterns in Mexico City after the 1985 Michoacán earthquake demonstrated conclusively the significant effects of local site conditions on the seismic response of the ground. Peak accelerations of incoming motions in rock, generally less than 0.04 g, were amplified about five times on the clay soils of the old lakebed, with devastating effects for structures with periods close to site periods. Similarly, Housner (in Finn 1994) points out that in the 1989 Loma Prieta earthquake major damage occurred on soft sites in the San Francisco-Oakland region, where the spectral accelerations were amplified two to four times above adjacent rock sites. Similarly, the research of Rebez, Peruzza et al. (1999) demonstrated that soil condition was a first-order factor influencing the level of the expected shaking, with an average increase of about 0.2 g for the prediction related to a 475-year return period for Italy, when passing from rock to soft soil. Table 3.2 illustrates the amplification factors applied on the basis of local soil maps.

Soil Class	Factor	Description
A	0.7	Hard rock
B	0.8	Rock
C	1.0	Very dense soil and soft rock (firm ground reference condition)
D	1.5	Stiff soil
E	2.0	Soft soil
F	2.0	Special soils likely to liquefy or otherwise fail

Table 3.2: Soil Factors Affecting PGA (Emergency Preparedness Canada 1999)

Topographic Effects

Castro (1999) considers that the variation in intensity occurs due to the roughness or irregularity of the topography. Additional authors (Sauter 1989; Urban 2002) found that topography has a significant influence on the intensity of the ground motion, and that the effect can be either amplification or attenuation. Mulas de la Peña (1995) points out that the geological conditions have an equally meaningful influence; thus, if the edges of the valleys are constituted of unconsolidated soils, the amplifying effect can yet be even greater.

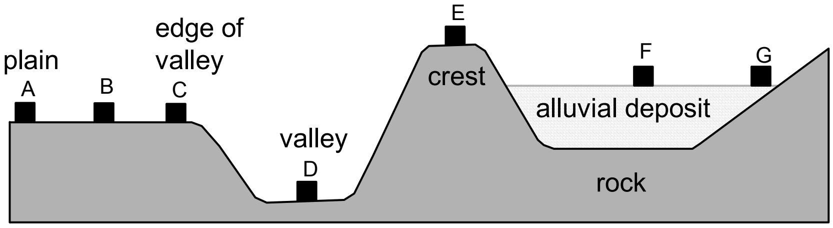

Figure 3.9: Site Effects on Ground Motion (Sauter 1989)

Figure 3.9 illustrates the results of a research by Vogt (1987), who concluded that PGA near the valley (site B) is amplified by 50% with respect to a flat terrain (site A), while at the edge of the valley (site C) amplification was twice that of the reference value; at the bottom of the valley (site D) an attenuation exists and therefore PGA is reduced by 65%.

According to Urban (2002), some relationships have been established based on differences in the length, width or height of the topography. Others such as Mulas de la Peña (1995) approached this from the point of view of geometry from the base of a riverbed or ravine. He concluded that the maximum amplification factors were obtained at the crests of the slopes with higher inclination. Castro (1999) correlated geometry with the damage observed from the 1999 Armenia-Colombia earthquake collected as the part of the Rapid Inventory of Earthquake Damage (RIED) project (ITC, TU Delft et al. 2000).

There are differences of opinion related to the maximum distances from the borders of hillsides or scarps where building damage is above average. For example, Geli et al. (in Urban 2002) consider that the effects exist up to a distance of 200 m, whereas Castro (1999) considers that the distance is 70 m. Despite the differences of opinion related to the figures, there is consensus about the correlation between damage of buildings and borders of hillsides or scarps.

As Sauter (1989) pointed out, despite recognition of the effect of topography on the intensity of ground motion, no appropriate methods to quantify this have been developed and therefore building codes currently lack this consideration.

3.2.7 Building Response

The response of a building to ground motion is as complex as the ground motion itself, yet typically quite different. Buildings also begin to vibrate in a complex manner and, because this is a vibratory system, it also possesses a frequency content. The building's vibrations, however, tend to centre around one particular frequency, which is known as its natural or fundamental frequency. In general, the lower a building is, the higher its natural frequency; the taller the building is, the lower its natural frequency.

An important quality of a building’s response is the building's natural period. The building period is simply the inverse of the frequency: whereas the frequency is the number of times per second that the building will vibrate back and forth, the period is the time it takes for the building to make one complete vibration.

This means that a very tall building with a low natural frequency has a high natural period. For example, it takes a skyscraper a comparatively long time to sway back and forth during strong wind (see Figure 3.10). Table 3.3 below provides a representative range of building heights and natural periods:

Height (in storeys)	**Typical Natural Period (s)**	**Typical Frequency** in cycles/second (Hz)
2	0.2	5.0
5	0.5	2.0
10	1.0	1.0
20	2.0	0.5
30	3.0	0.3

Table 3.3: Natural Periods and Frequencies per Building Height

When the frequency content of the ground motion is centred on the building's natural frequency, resonance occurs which tends to increase or amplify the building's response. Due to this, buildings suffer the greatest damage from ground motion at a frequency close or equal to their own natural frequency.

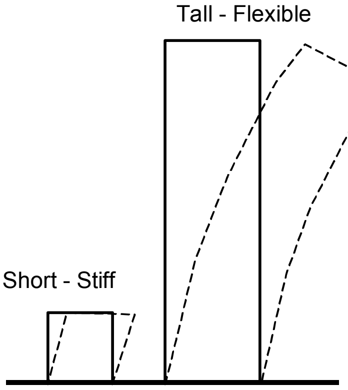

Figure 3.10: Building Height, Stiffness and Period (USGS 1997)

The Mexico City earthquake of 19 September 1985 provides a striking illustration of this. The majority of the many buildings that collapsed during this earthquake were around 20 storeys high and therefore had a natural frequency of around 2.0 Hz. These 20-storey buildings were in resonance with the frequency contents of the 1985 earthquake. Other buildings of different heights and with different vibrational characteristics were often found undamaged, even though they were located right next to the damaged 20-storey buildings.

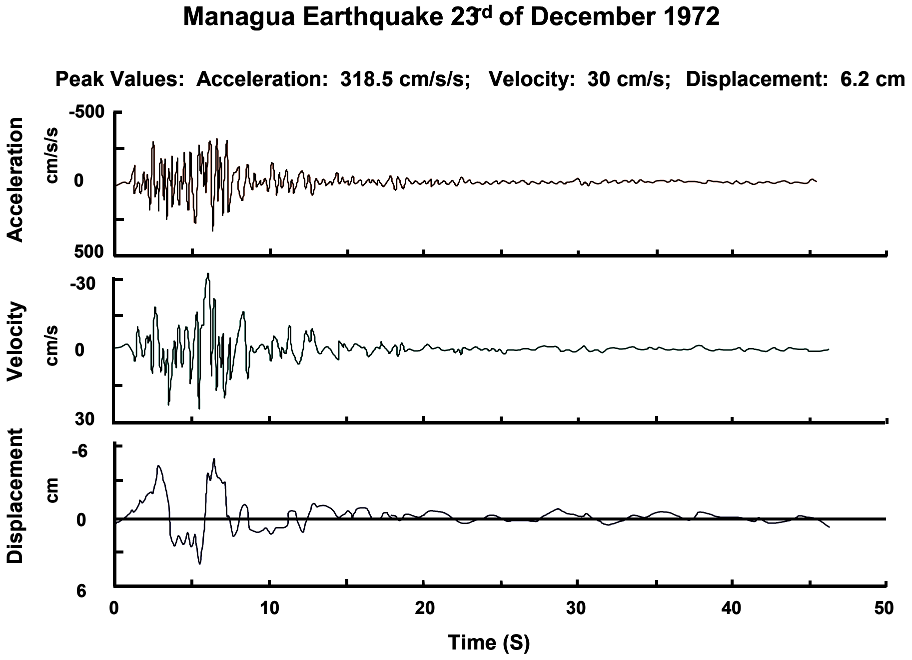

Figure 3.11: Ground Acceleration Record (Sauter 1989)
(record typical of a nearby earthquake: high frequencies and high horizontal acceleration)

Different buildings can respond in widely differing manners to the same earthquake ground motion. Conversely, a given building will act differently during different earthquakes. This phenomenon highlights the need to concisely represent the building's range of responses to ground motion of different frequency contents. Such a representation is known as a response spectrum. A response spectrum is a graph that plots the maximum response values of acceleration, velocity and displacement against period and frequency. Such response spectra are very important in earthquake engineering.

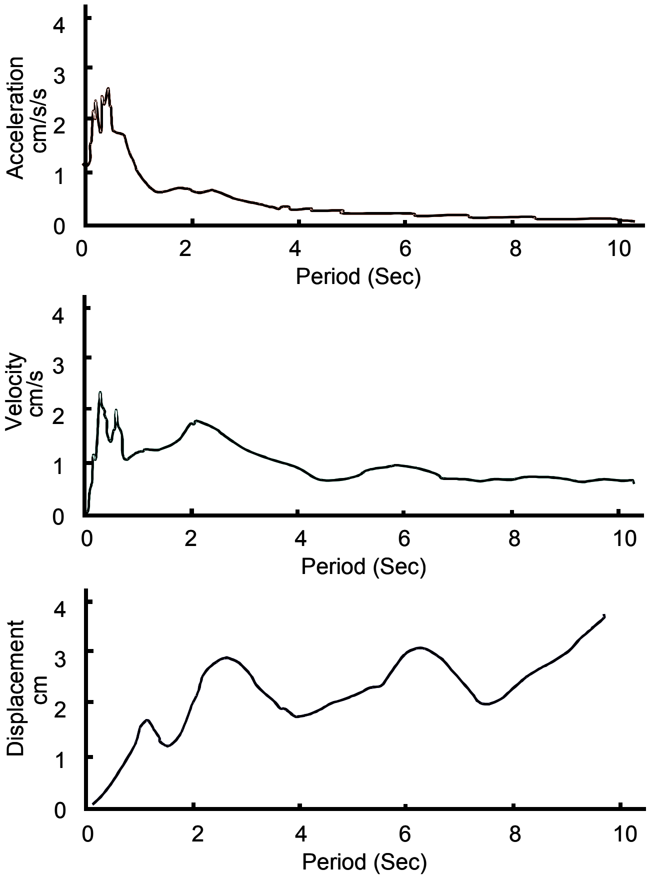

Figure 3.12: Simplified Response Spectra (Sauter 1989)

Figure 3.12 illustrates a response spectrum. It shows how building response characteristics vary with building frequency and period. As building period lengthens, accelerations decrease and displacement increases. On the other hand, buildings with shorter periods (but higher natural frequencies) undergo higher accelerations but smaller displacements. The amount of acceleration that a building undergoes during an earthquake is a critical factor in determining how much damage it will suffer. The spectra in Figure 3.10 provide some indication of how accelerations are related to frequency characteristics. Figure 3.9 shows one way in which response spectra can be useful, since identifying the resonant frequencies at which a building will undergo peak accelerations is one very important step in earthquake resistance.

The damage that a building suffers primarily depends not upon its displacement but upon acceleration. Whereas displacement is the actual distance the ground and the building may move during an earthquake, acceleration is a measure of how quickly they change speed as they move. During an earthquake, the speed at which both the ground and building are moving will reach some maximum. The more quickly this maximum is reached, the greater their acceleration.

Acceleration has an important influence on damage because, as an object in movement, the building obeys Newton's Second Law of Dynamics. The simplest form of the equation expressing the Second Law of Motion is: $F = M.A$

This states the *F*orce acting on the building is equal to the *M*ass of the building times the *A*cceleration. As the acceleration of the ground, and in turn of the building, increases, so does the force that affects the building, since the mass of the building is constant.

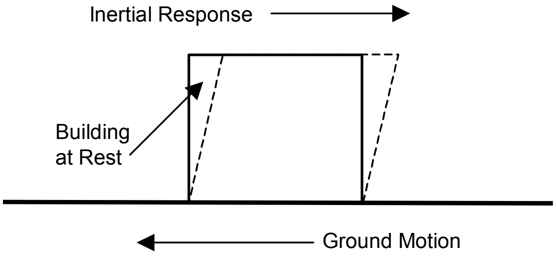

Figure 3.13: Acceleration, Inertial Forces (USGS 1997)

The greater the force affecting a building (refer to Figure 3.13), the more damage it will suffer; decreasing *F* is an important goal of earthquake-resistant design. When designing a new building, for example, it is desirable to make it as light as possible, which means of course that *M*, and in turn *F*, will be lessened.

F is an inertial force, that is, the force is created by the building's tendency to remain at rest and in its original position, even though the ground beneath it is moving. This inertial force *F* imposes strains upon the building's structural elements. These structural elements primarily include the building's beams, columns, load-bearing walls and floors, as well as the connecting elements that tie these various structural elements together. If these strains are large enough, the building's structural elements will suffer various types of damage.

The magnitude of the building’s response (the accelerations that it undergoes) depends primarily upon the frequencies of the input ground motion and the building's natural frequency. When these are near or equal to each other, the building's response reaches a peak level. In some circumstances, this dynamic amplification effect can increase the building's acceleration to a value two times or more that of the ground acceleration at the base of the building. Generally, buildings with higher natural frequencies and a short natural period tend to suffer higher accelerations but smaller displacement. In the case of buildings with lower natural frequencies and a long natural period, this is reversed: the buildings will experience lower accelerations but larger displacements.

As stated before, the taller a building, the longer its natural period tends to be. But the height of a building is also related to another important structural characteristic: the building flexibility. Taller buildings tend to be more flexible than short buildings. Therefore, a low building tends to be stiff, while a taller building tends to be flexible.

Stiffness greatly affects the building's uptake of earthquake-generated force. Ductility is the ability to undergo distortion or deformation such as bending without resulting in complete breakage or failure. The ductility of a structure is one of the most important factors affecting its earthquake performance. One of the primary tasks of an engineer designing a building to be earthquake-resistant is to ensure that it will possess sufficient ductility to withstand the size and types of earthquakes it is likely to experience during its lifetime.

Ground and building motion during an earthquake has a complex, vibratory nature. The building actually moves back and forth in many different horizontal directions. All vibrating objects, including buildings, tend to eventually stop vibrating as time goes on. More precisely, the amplitude of vibration decays with time. Without damping, a vibrating object would never stop vibrating once it had been set in motion. All buildings possess some intrinsic damping. The more damping a building possesses, the sooner it will stop vibrating, which of course is highly desirable from the standpoint of earthquake performance.

3.3 CONCLUSIONS

It was concluded that the triggering effects of natural phenomena are an important consideration in scenario development. It was also concluded that unless hazard maps have been developed on the basis of a complete earthquake catalogue and have been calibrated for local soil and topography, the results of an urban risk assessment are likely to be inaccurate. Finally, since one important cause of building damage is resonance, risk assessment should be developed for typical resonant frequencies.

Chapter Four: METHODOLOGY REVIEW

This chapter reviews the opinions and approaches to earthquake damage assessment of different groups and presents a summary of the strengths and problems detected. In Chapter Five, the case study is introduced. A review is made of the current legal framework regulating urban planning and disaster management.

4.1 INTRODUCTION

Contact was established with many government agencies, research centres and software developers around the world in the search for detailed technical information on their views and findings, or any particular method they had developed for assessing building risk. Many of those contacted, particularly the software manufacturers, have unfortunately responded with comments such as “for obvious reasons we can not give you the details …”. This seems to imply there is considerable profit resulting from loss predictions and that this information is valuable to users beyond the public planning environment. It would appear that many of these methodologies were developed for the insurance industry and, therefore, they are considered “secret assets” due to their high commercial value and are not readily available to the general public.

Several previous research methods will be described to better explain the approaches to risk assessment that have been used and to be able to identify their methodological constraints.

4.1.1 Small-Scale Approaches

In China, Chen, Chen et al. (1997) use GDP (gross domestic product) instead of building stock considerations, since they believe that the number of man-made facilities is directly proportional to GDP. Their approach, however, does allow the production of a city risk zonation map. Their method is based on a macroscopic index of exposure and population distribution. Since GDP figures are rarely available at regional or local level, the method can be used for establishing only risk at national level and only for macro-economic planning.

Papadopoulos and Arvanitides (1996) have developed a quantitative approach for assessing the earthquake risk for each of the 23 regions of Greece. Their method is therefore applicable to large scales. Age of construction, average population density and regional GDP per capita are the parameters used. The construction age is used as the authors consider that the year of implementation of the building code constitutes a turning point in the increased earthquake resistance or decreased vulnerability of the structures. The benchmark, however, is not the year of implementation itself (1959) but 1965, as they consider some time is needed for adjusting to new regulations. Population vulnerability is assessed by means of flat population densities. Since this method is intended for estimating regional risk, an assumption has been made that the relative value of the elements at risk is proportional to the regional GDP per capita. The results are reclassified and presented on a five-class qualitative scale (very low, low, intermediate, high and very high).

At the John A. Blume Earthquake Engineering Centre at Standford University, Davidson (1997) developed a composite specific risk index, referred to as the Urban Earthquake Disaster Risk Index (EDRI), to allow a comparison of the relative overall earthquake disaster risk of cities worldwide. The objective therefore is to produce not zonation maps but rather a simple indicator (see Figure 4.1). EDRI assesses the specific risk for a city as a whole, not for a specific site.

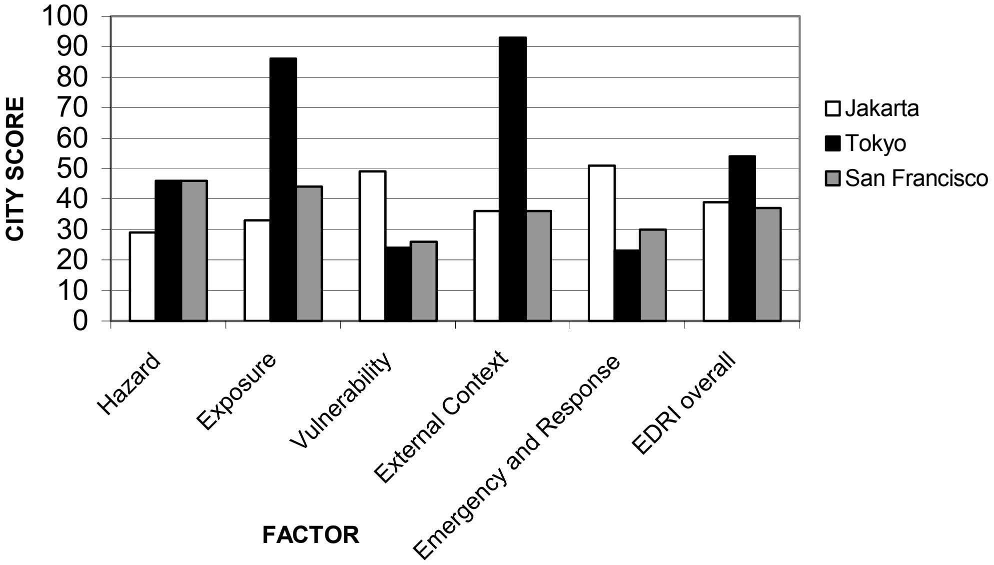

Figure 4.1: Comparison of EDRI Results (Davidson 1997)

EDRI considers factors that contribute to the specific risk whereas loss estimation models aim at estimating the expected consequences of future earthquakes (i.e. deaths, injuries, damaged buildings, economic loss). The main headings (refer to Figure 4.2) that are identified as contributing factors in EDRI are:

- Hazards: magnitude, spatial distribution and frequency of the geological triggering phenomena
- Exposure: size of the city measured in terms of quantity of people and physical objects as well as amount and types of supported activities
- Vulnerability: the ease with which exposed people, physical objects and activities may be affected
- External context: the way in which impact within a city affects people and activities outside the city
- Emergency response and recovery capability: the way in which a city can effectively and efficiently reduce the consequences of an earthquake through formal and organised efforts

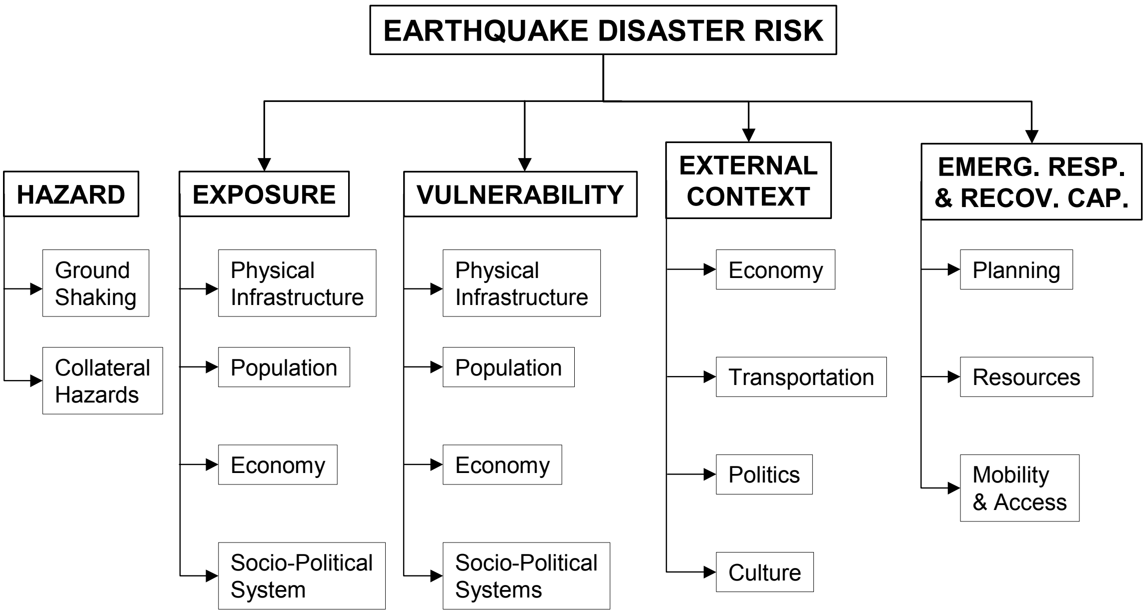

Figure 4.2: Conceptual Framework of EDRI (source: Davidson 1997)

One or more simple and measurable indicators (see Table 4.1) are used to represent each of the broad abstract criteria presented (refer to Figure 4.1). The indicators have been chosen on the basis of:

- Validity: the indicator accurately represent the factors for which they are proxies
- Data availability and quality: indicators are measured using data that is reliable, available in a consistent form from around the world, and relatively easy to collect
- Quantitativeness and objectivity: indicators are easily evaluated and understood
- Comprehensible: indicators should be understandable; familiar concepts and measuring systems should be used
- Directness: indicators measure the concept of interest itself

The index illustrates (see Figure 4.1), for example, that the specific risk (EDRI) in Jakarta is about equal to that of San Francisco but significantly less than that of Tokyo. It also indicates that the specific risk in Jakarta is caused mostly by high vulnerability and insufficient emergency response and recovery capability. The specific risk in San Francisco results from the high frequency of earthquakes, while in Tokyo it results from the vast number of people and structures exposed.

Several approaches leading to the production of seismic risk information of higher spatial resolution will be discussed next. In Costa Rica, Montero and Rodríguez (1990) have classified the building stock according to the census tract data. The parameters they used were:

Ground Shaking	• Exp (MMI w/50-year return period • Exp (MMI w/500-year return period • Percentage of urbanised area w/soft soil
Collateral Hazards	• Percentage of urbanised area with high liquefaction susceptibility • Percentage of buildings that are wood • Population density • Tsunami potential indicator
Physical Infrastructure Exposure	• Population • Per capita GNP, constant 1999 US$ figure • Number of housing units • Urbanised area
Population Exposure	• Population
Economy Exposure	• Per capita GNP, constant 1990 US$ figure
Physical Infrastructure Vulnerability	• Seismic code indicator • City wealth indicator • City age indicator • Population density • City development speed indicator
Population Vulnerability	• Percentage of population aged 0-4 or above 65
Economic External Context	• Economic context indicator
Political External Context	• Political country context indicator • Political world context indicator
Planning	• Planning indicator
Resources	• Per capita GNP, constant 1990 US$ figure • Ten-year average of annual real growth in per capita GNP • Housing vacancy rate • Number of hospitals per 100,000 people • Number of physicians per 100,000 people
Mobility and Access	• Extreme weather indicator • Population density • City layout indicator

Table 4.1: EDRI Sample Analysis Indicators (Davidson 1997)

- building material (i.e. adobe, wood and concrete)
- maintenance level (i.e. good, regular, poor)
- land-use, since they consider that building code enforcement is lower in residential areas compared with other land-uses

To establish the population vulnerability they used a flat population density figure only. The result is a risk zonation with no further analysis of the economic losses that this could imply.

			Probability of Damage (%) by Intensity (MMI) and Damage State						
Damage State	**Damage Factor Range (%)**	**Central Damage Factor (%)**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
1. None	0	0	3.7						
2. Slight	0-1	0.5	68.5	26.8	1.6				
3. Light	1-10	5	27.8	73.2	94.9	62.4	11.5	1.8	
4. Moderate	10-30	20			3.5	37.6	76.0	75.1	24.8
5. Heavy	30-60	45					12.5	23.1	73.5
6. Major	60-100	80							1.7
7. Destroyed	100	100							
Mean Damage Factor (MDF) (%)			**1.73**	**3.79**	**5.45**	**10.6**	**21.4**	**25.5**	**39.4**

Table 4.2: DPM for Wood-Frame Structure Type According to MMI (ATC (Applied Technology Council) 1985)

In California, King and Kiremidjian (1999) have used the ATC-13 (California Earthquake Damage Data) classification of building structures, which subdivides buildings into 15 classes. However, because of the degree of uncertainty in the ground visual inspections, they insist on the need to aggregate the results to a lower spatial resolution – in this case the census track level. Damage ratios derived from the ATC-13 damage data were produced to depict building vulnerability (see Table 4.2 and Figure 4.3). Population vulnerability is addressed by using flat population densities overlaid onto building vulnerability, meaning that it is a “mirror” function of building vulnerability. Their approach describes the quantification of the economic losses by multiplying the area of the building by the present construction cost for that type of building.

4.1.2 Large-Scale Approaches

ATC-13 presents historical damage data in the form of damage probability matrixes (DPM) such as that of Table 4.2. A DPM relates the probabilities of reaching or exceeding the damage state as a function of the ground motion intensity according to the Modified Mercalli Intensity (MMI) (for a description of the MMI, refer to Chapter 3 and Appendix I). The mean damage factor (MDF) for a construction class exposed to the same level of intensity is the product of the central damage factor and the associated probabilities. The MDFs can be used to depict the overall building vulnerability (see Table 4.2). The Applied Technology Council (ATC) defines the percentage financial loss in terms of “damage factor” as follows:

$$D_F = D_L / R_v$$

Where:
D_F: damage factor
D_L: dollar loss
R_v: replacement value

Cardona (1997) modified the ATC-13 classification to better reflect the Colombian building stock. He added the construction year of the building since he considered that it was evident from damage data that pre-seismic-code buildings were bad performers. He used ATC-13 damage curves, although slightly modifying them. Similarly to King and Kiremidjian (1999), he collected information at individual building level but aggregated it later to a lower spatial resolution that he called “cells”. Population vulnerability was addressed by using a flat population density, although two scenarios (a night and a day scenario) were used to depict commuting trends.

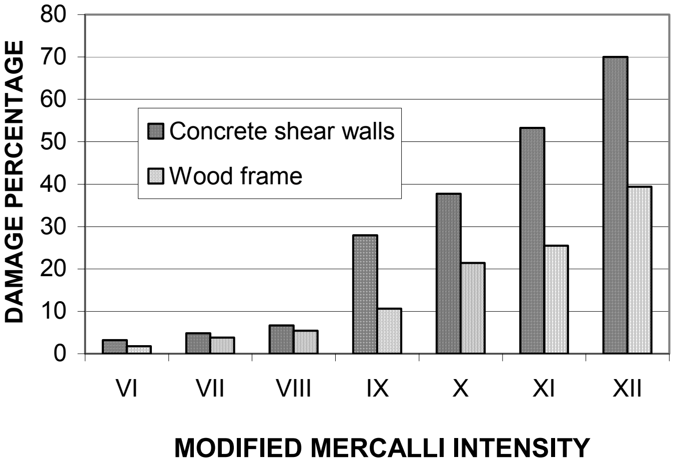

Figure 4.3: Comparison of Building Vulnerability for Two Types of Structures (based on ATC-13 mean damage ratios)

In Italy, Menoni, Petrini et al. (1997) used a quite different approach. Buildings were divided into four classes according to their maintenance condition, but then they rated them according to the degree of compliance with the construction code, relying on ground visual observations. The method for establishing social and economic losses was not discussed.

In Turkey, Erdik and Swift-Avci (1997) performed an interesting test for assessing present risk in old Istanbul, using Turkish earthquake data as well as ATC-13 and other damage data sources in order to compare the differences and similarities between the results.

The National Institute of Building Sciences (NIBS) developed a methodology referred to as HAZUS (National Institute of Building Sciences (NIBS) 1999) for assessing earthquake risk in the USA. This methodology was developed for the Federal Emergency Management Agency (FEMA). The goal of FEMA was to provide federal, state and local agencies, as well as other public and private organisations, with a methodology that was not only reliable but would also allow comparisons between different areas.

Generally speaking, this constitutes a more sophisticated approach than those previously discussed. Damage predictions for model building types for a given level of ground shaking are developed as the basis for estimating:

- Casualties due to structural damage
- Monetary losses due to building damage (i.e. cost of repairing or replacing damaged buildings and their contents)
- Monetary losses resulting from building damage and closure (e.g. losses due to business interruption)
- Social impacts (i.e. loss of shelter)
- Other economic and social impacts

NIBS (1999) developed functions for estimating building damage due to ground shaking. The extent and severity of damage to structural (and non-structural) components of a building are described by one of five damage states**:** *None*, *Slight*, *Moderate*, *Extensive* and *Complete*. The functions that were developed for estimating building damage due to ground shaking include:

- Fragility curves that describe the probability of reaching or exceeding different states of damage given peak building response
- Building capacity (push-over) curves that are used (with damping-modified demand spectra) to determine peak building response

HAZUS uses a technique to estimate peak building response as the intersection of the building capacity curve and the response spectrum shaking demand at the building's location demand spectrum.

The building capacity curves developed for HAZUS are based on engineering design parameters and judgment. According to NIBS (1999), three control points that define model building capacity describe each curve:

- Design capacity
- Yield capacity
- Ultimate capacity

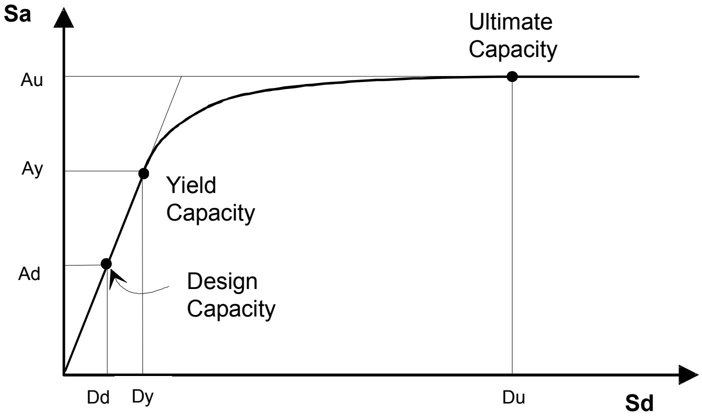

Figure 4.4: Example Building Capacity Curve (NIBS, 1999)
Sa=spectral acceleration, Sd=spectral displacement

- *Design capacity* represents the nominal building strength required by current model seismic code provisions (e.g. National Institute of Building Sciences (NIBS) 2001), or an estimate of the nominal strength for buildings not designed for earthquake loads. Wind design is not considered in the estimation of design capacity, and certain buildings (e.g. tall buildings located in zones of low or moderate seismicity) may have a lateral design strength considerably greater than that based on seismic code provisions.

- *Yield capacity* represents the true lateral strength of the building, considering redundancies in design, conservatism in code requirements and true (rather than nominal) strength of materials.
- *Ultimate capacity* represents the maximum strength of the building when the global structural system has reached a fully plastic state. Ultimate capacity implicitly accounts for loss of strength due to shear failure of brittle elements. Typically, buildings are assumed capable of deforming beyond their ultimate point without loss of stability, but their structural system provides no additional resistance to lateral earthquake force.

These fragility curves (see Figure 4.5) describe the probability of being in a specific damage state and they express damage as a function of building displacement. Peak ground acceleration (PGA) is used rather than the Modified Mercalli Scale (for equivalent MMI values for PGA, refer to Appendix I). The PGA allows for more precision as probabilities are not given at an ordinal scale but at a continuous scale; however, depending on the contents of the hazard mapping, it may provide no advantage over the MMI.

The above method used the ATC-13 classification, although the building type “mobile homes” was added to the classification. This classification is enhanced by further subdividing the building types according to the number of storeys, giving a total of 36 classes. A parameter is incorporated related to compliance with building code regulations: *pre-code*, *low / medium / high code* compliance.

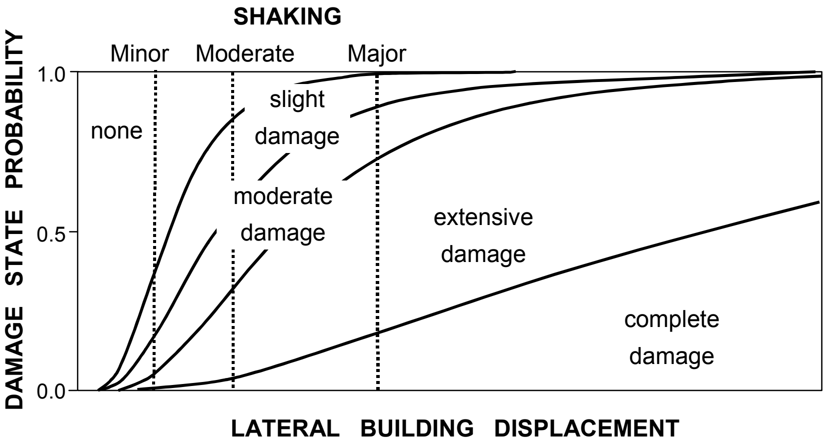

Figure 4.5: Example of Fragility Curves (National Institute of Building Sciences (NIBS) 1999)

The historical building damage and casualty data used is “global” in nature, as the California damage data contained in the ATC-13 database (known as ATC-13d) was combined with data from other countries. FEMA considered this necessary since ATC-13d contained limited data on the total collapse of buildings and it was believed that by incorporating data from the earthquakes in El Salvador, Mexico and Armenia (former USSR), the forecasts would be more reliable. The damage data is presented in the form of fragility curves (see Figure 4.5).

The breakdown into five damage states is used not only to calculate the cost of damage to the building stock but also to calculate casualties, injuries and shelter needs. For example, NIBS (1999) assumes that there is a strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. It considers that in smaller earthquakes, non-structural damage will most likely control the casualty estimate, while in severe earthquakes (where there will be a large number of collapses and partial collapses) there will be a proportionately larger number of fatalities. The total floor area of buildings within the “complete” damage state is therefore used to estimate the number of casualties (refer to Figure 4.6).

The casualty output consists of four injury severity levels (first proposed by Durkin and Thiel (1993)) presented at the census tract level. Table 4.3 defines the injury classification scale used in HAZUS. NIBS (1999) considers that the selected four-level injury scale represents an achievable compromise between the demands of the medical community (in order to plan their response) and the ability of the engineering community to provide the required data. For example, medical professionals would like to have the classification in terms of "injuries and illnesses" to account for worsened medical conditions caused by an earthquake (e.g. heart condition). However, currently available casualty assessment methodologies do not allow a finer resolution in the casualty scale definition.

Severity Level	**Injury Description**
1	Injuries requiring basic medical aid without requiring hospitalisation
2	Injuries requiring a greater degree of medical care and hospitalisation, but not expected to progress to a life-threatening status
3	Injuries that pose an immediate life-threatening condition if not treated adequately and expeditiously. The majority of these injuries are the result of structural collapse and subsequent entrapment or impairment of the occupants.
4	Instantaneously killed or mortally injured

Table 4.3: Injury Classification Scale
(National Institute of Building Sciences (NIBS) 1999)

To assess the population vulnerability, a three-scenario approach was adopted (2 a.m., 2 p.m. and 5 p.m.). The reasoning behind these scenarios is not explained by NIBS but it is probably the following:

- 2 a.m. depicts the population densities when people are at home
- 2 p.m. depicts the population densities when people are at work or school
- 5 p.m. depicts the population densities when people are commuting

One interesting aspect relates to fatalities in the commuting population being established as a percentage of people located under or on bridges or overpasses.

Damage probabilities per structural damage states (slight, moderate, extensive and complete) are used to calculate the number of people in each of the injury severity levels. The casualty rates used in HAZUS are relatively uniform across building types for a given damage level, with differentiation to account for types of construction that pose higher than average hazard at moderate damage levels (e.g. falling of pieces of un-reinforced masonry) or at severe levels (e.g. complete collapse of heavy concrete construction as compared with wood-frame construction). Rates used in the ATC-13 method were evaluated and revised based on comparison with a limited amount of historical data. According to NIBS (1999), in the Northridge earthquake of 1994, the casualties estimated by HAZUS are a reasonable representation of the actual numbers observed.

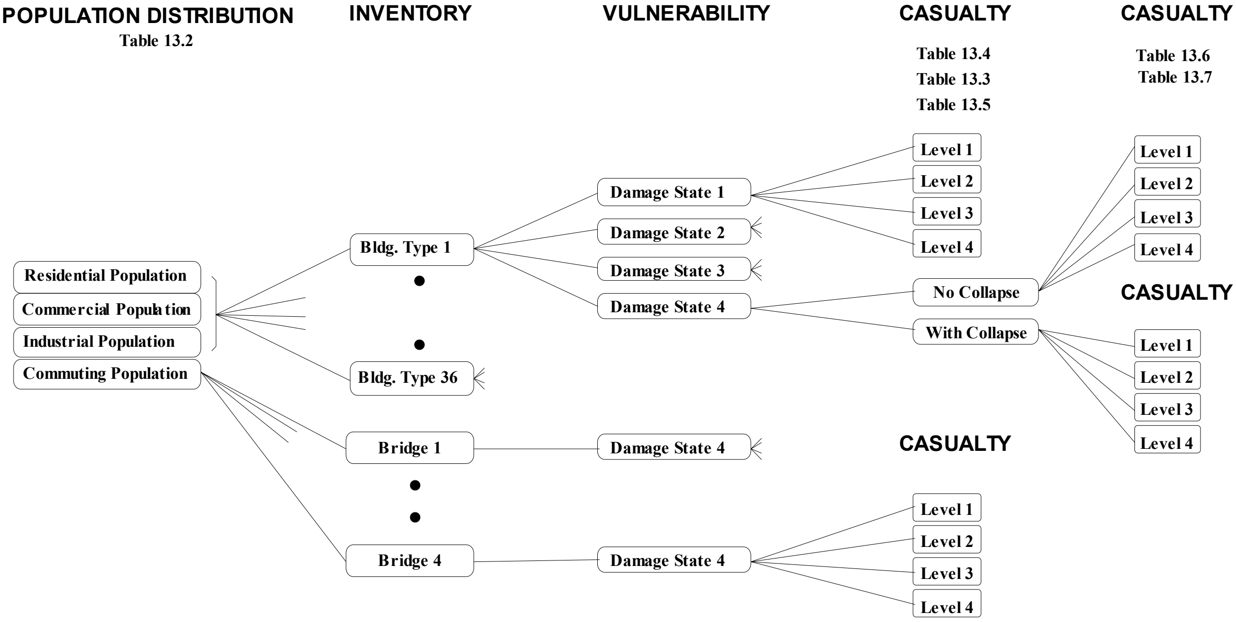

Figure 4.6: Conceptual Flow Methodology of Casualty Estimation
(National Institute of Building Sciences (NIBS) 1999)

The final casualty output produced by HAZUS is (refer to Figure 4.6):

- Casualty rates by model building type for slight structural damage (damage state 1)
- Casualty rates by model building type for moderate structural damage (damage state 2)
- Casualty rates by model building type for extensive structural damage (damage state 3)
- Casualty rates by model building type for complete structural damage (damage state 4) without structural collapse
- Casualty rates by model building type for complete structural damage (damage state 4) with structural collapse

One of the strengths of the method is that it distinguishes between “regular” and “essential” facilities. Bolt (1994) considers that one of the lessons after the 1989 Loma Prieta earthquake in California was the seismic fragility of many crucial facilities. He argues that, in decision-making on risk reduction, the failure to allow for the functioning of key institutions such as hospitals, banks and utilities as well as life safety can have the gravest consequences. “Essential” facilities are those vital to emergency response and recovery following a disaster and therefore include medical care facilities, emergency response facilities and schools. School buildings are included because they often play a key role in housing people displaced from damaged homes. This highlights the fact that emergency and relief planning considerations are being carefully addressed by NIBS. Generally there are very few of each type of essential facility (if any) in a census tract, making it easier to obtain site-specific information for each facility. For “essential” facilities, a thorough building-by-building inspection is suggested, along with computer structural response modelling.

In HAZUS, the general building stock is inventoried by calculating, for each census tract, the total area of groups of buildings with specific characteristics (i.e. calculating the total area of low-rise un-reinforced masonry structures). The methodology is therefore based on the census tracts as the smallest geographical unit. Census tracts are divisions of land that are designed to contain 2,500 to 8,000 inhabitants with relatively homogeneous population characteristics, economic status and living conditions. For this reason the physical area within census tracts will vary depending on the density of the population. In densely populated regions census tracts can be a few city blocks, whereas in rural areas a census tract may be many square miles. Census tract divisions and boundaries change only once every 10 years. Census tract boundaries never cross county boundaries; hence they can completely and uniquely define all the area within a county. This characteristic allows a unique division of land from country to state to county to census tract (National Institute of Building Sciences (NIBS) 1999).

NIBS considers that collecting even this “simplified” inventory can be problematic, as there are rarely reliable and complete databases that provide the necessary information (i.e. building size, building occupancy, building height, structural system).

It therefore proposes two possible methods for capturing data for creating an inventory of regular buildings:

- Application of a set of guidelines called “Rapid Visual Screening of Buildings for Potential Seismic Hazards (Applied Technology Council (ATC) 1988). Broadly speaking, the screening of regular buildings requires a sidewalk inspection lasting between 15 and 20 minutes per building.
- Inferences about large groups of buildings based on land-use patterns; for example, if this is a residential area, 50% of the buildings are single-family wooden structures and

> 50% are multi-family wooden structures. NIBS (1999) considers that there are inaccuracies in the inventory of general building stock due to inferences made. The error tends to be random and can be accounted for in the probabilistic aspects of the methodology.

The approach used in Canada, (Emergency Preparedness Canada 1999) involves calculating damage to buildings and casualties on the basis of MMI values. For different building types, damage severity rates are generated for each intensity level. Three types of casualties (i.e. minor, major, death) are calculated on the basis of the 7 damage severity levels. The damage rates are also used to calculate the number of people in need of temporary shelter.

In contrast to all the above, Kappos, Stylianidis et al. (1998) use an analytical method for reviewing buildings rather than empirical-statistical methods (see Figure 4.7). Analytical damage data (left) is produced either from a computer simulation or from a scale model tested on a shaking table. Empirical damage data (right) is produced from visual observations from a past event. These authors' approach uses analytically calculated damage indices by means of computer modelling Greek buildings according to their structural design. It is important to mention this method since it constitutes the most time-consuming approach to building vulnerability determination and one that requires highly specialised professionals and computer equipment for a building-by-building analysis.

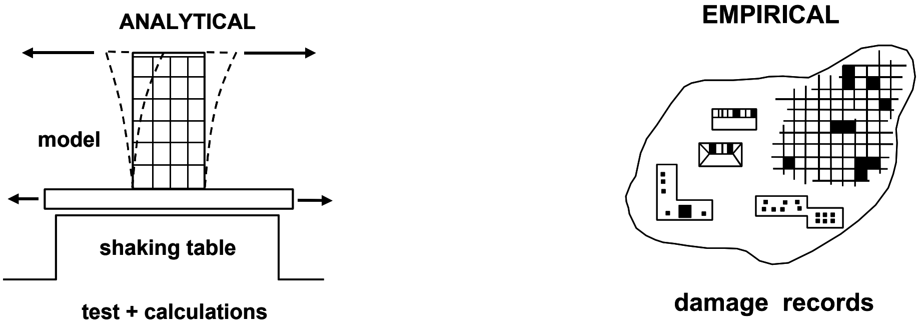

Figure 4.7: Types of Earthquake Damage Data (United Nations Disaster Relief Co-ordinator 1991)

Alexander (1993) considers that even though configuration is not likely to be the sole cause of building failure, it may be a major contributor. He points out that historically, before the use of steel and reinforced concrete construction, good configuration was one of the major determinants of good seismic performance. Building plans tended to be symmetrical; spans were short so that there was a high density of supporting walls and the need for massive load-bearing construction. However, this increased earthquake forces in the building and tended to keep unit stresses in the materials to very low values.

Similarly, Davidson (1997) points out that the vulnerability of single structures can be assessed according to the following criteria:

- Structural system and construction material, since a structure should be able to undergo long-duration horizontal and vertical shaking without excessive loss of stiffness or strength.
- Configuration should be regular and symmetrical to minimise torsional response, and the elevation should have no great discontinuities in stiffness, strength or mass.
- Structural continuity, as structural elements should be tied together so that they shake as a single unit.
- Changes in structural condition because of the effects of aging, maintenance, damage in previous earthquakes and retrofitting.

Rojahn (1994) considers that, although there are exceptions, good earthquake performers normally have the following characteristics:

- They are constructed of materials that can undergo long-duration horizontal and vertical shaking without excessive loss of stiffness or strength.
- They are based on firm foundation materials (the structure does not tip or settle due to foundation failure).
- They have regular, symmetrical plan shapes (so that torsional response is not induced in the structure).
- They are composed of structural elements that are tied together (the structural elements do not separate during earthquake shaking).
- They are not too close to other structures (so as to avoid two structures pounding against each other).
- They have not previously been damaged by an earthquake.

4.2 PROBLEMS DETECTED

4.2.1 Risk Modelling

After reviewing the different approaches, the problems identified are summarised as follows:

- The most obvious difficulty is when no mention is made of the characteristics of the building stock. It can be argued that this approach could be acceptable for deriving population vulnerability for some types of natural hazards, since one could drown during a flood without the built environment playing a role. The ground shaking from an earthquake, however, is not enough to kill human beings; it is by interacting with the built environment that people become vulnerable. The type of structure constitutes a strong parameter, although there are other issues that also play an important role (i.e. configurational aspects, age of construction). On the other hand, when GDP is substituted for building stock considerations, the built environment is seen as homogeneous and the results obtained would be unreliable for urban policy making. Bendimerad (1997) considers that the lack of building inventories significantly impairs progress in assessing risk to large areas and that effective non-time-consuming data collection methods are urgently needed. Steinberg (1998), for example, warns against the danger of putting too much emphasis on urban economics, finance and public administration and only a very marginal focus on the built environment of cities.

- One important drawback of specific risk assessments such as EDRI is that they do not allow validation.

- It is very surprising to see that there is no mention in any of these studies about the dilemma presented by buildings of high cultural/historical value that have a high vulnerability.

- Another problem refers to the selection of land-use mapping as a criterion for establishing the economic value of the built environment. Land-use mapping alone is not accurate since it only gives an insight into the concentration of economic activities. For example, land-use maps typically do not include information about the number of storeys of buildings and therefore they must be used in combination with other data to derive information about the economic value of the built environment. Information about the area of construction could be derived by using data acquisition techniques such as aerial photography.

- Another weakness relates to using flat population density maps to represent the vulnerability of the population. Firstly, people are not “fixed to the ground” throughout the day, for example they commute to work and to school. For this reason, population densities throughout the day change considerably. One could then argue that the population densities typically produced by census bureaux reflect the situation only during the night since the source of this information is the number of people that inhabit a home. This is therefore not reliable information to be used for emergency planning for a “week-day 11 a.m. scenario”, for example. Kakhandiki and Shah (1998) consider that information about the temporal variations of risk, attributable to changes in the human component of natural disasters, is rarely included in disaster assessment carried out by hazard management professionals. Uitto (1998) mentions the differences between densities during night-time, daytime and commuting periods.

  Secondly, people are not equal in terms of mobility and dependency. In reality, people are more or less mobile depending on age, gender or mental health. Shoaf, Sareen et al. (1998) consider that children, women and the elderly are at increased risk of injury and death. Moreover, they indicated that during the Kobe earthquake more than half of all fatalities were people over 60 years of age. Takahashi (1998) has also addressed the high vulnerability of the elderly. Smith (1996) indicated that amongst the dead in a flood in Bangladesh 50% were children under 10. Since this age group comprised 30% of the population, it was clear that the young were at higher risk. Hearn-Morrow (1999) considers all the following groups to be at higher than average risk: the elderly, the physically or mentally disabled, renters, poor households, women-headed households, ethnic minorities (by language), recent immigrants/residents, large households, children, the homeless and tourists/transients.

- A last problem relates to viewing the building stock's response to particular hazards in isolation. A type of building with low vulnerability to one type of hazard could have a high vulnerability to another type of hazard, hence the necessity to use an integrated approach that keeps the broader picture in mind at all times. The majority of natural hazard research has focused on single hazards but of course any city may be prone to more than one hazard type. This idea led to the concept of "all-hazards-to-a-place" (Hewitt et al. in Gatrell and Vincent 1991).

4.2.2 Data Capture

There are rarely reliable and complete databases that provide the necessary information on buildings (such as size, land-use, height and structural system) that could be used for loss estimation. To provide the required inputs for assessing risk, conceptual models are important; however, the financial and temporal implications of data capture and integration should be carefully analysed. This is of special importance in developing countries, where resources are scarce.

Two major problems are detected in terms of data capture:

- In the developing world, it is unreasonable (both from a temporal and a financial point of view) to collect building type information on an individual basis by either the rapid visual sidewalk screening or by analytical methods. Besides being slow and expensive, the production of building stock inventories by analytical methods demands highly trained personnel (i.e. civil engineers specialised in structural engineering), who are unlikely to be available in the numbers required for completing the task within acceptable time frames. Building inspectors and other less qualified personnel can carry out rapid visual screening of buildings. However, in countries where financial resources are not available for carrying out appropriate building inspection of ongoing construction, it is obvious that rapid visual screening of existing buildings is low priority.
- Making inferences about large groups of buildings rather than building-by-building inspection could provide the answer to building type inventories in the developing world. However, basing inferences about the building stock solely on land-uses, as suggested by NIBS, reflects a lack of knowledge about the urban development process. Although this method is financially and temporally feasible, it is highly unreliable as it does not

account for the historical changes in the use of construction materials and structural types, which occur due to increased knowledge and the enforcement of regulations.

4.3 CONCLUSIONS

It is considered that the methodology developed by NIBS is very comprehensive in terms of the modelling of urban earthquake risk and the outputs produced. Given the diversity of the building stock in the USA, its classification covers most building types and is therefore easily transferable to other countries. Considering the data input requirements and the complexity of the calculations this involves, however, their method is expensive and time-consuming. Conversely, the method developed by the Applied Technology Council (ATC-13), despite being more simplistic and less accurate, is more applicable in developing countries due to its data requirements. Moreover, it is easily transferable into a GIS environment and the outputs obtained are sufficient to carry out planning at, for example, the building block level which is adequate for strategic planning.

Chapter Five: METHODOLOGICAL APPROACH

Two methodologies are discussed; one deals with a rapid cost-effective method of collecting data for identifying relevant characteristics of buildings, while the second relates to the geographically referenced data integration necessary to assess population and building risk.

5.1 CONCEPTUAL MODEL

The conceptual model in Figure 5.1 was developed on the basis of the definitions by the United Nations presented in Chapter Two. The objective of the methodology is to assess earthquake risk by using either digital datasets that are typically available in developing countries or datasets that can be rapidly and cheaply generated. This methodology has therefore been developed for data-constrained and financially constrained local governments. The methodology applies to population and building earthquake risk. Due to time constraints, infrastructural risk, which is a key issue in disaster mitigation, is excluded from the research. The methodology consists basically of three components (refer to Figure 5.1): a) data input collection or compilation, b) data integration and c) information outputs.

The input data collection or compilation stage involves the hazard intensity maps (one map for each return period), the population and building vulnerability damage data, and the inventory of population and buildings (elements at risk), as well as the cost of buildings and salaries. In terms of the characteristics of these datasets, the cost data can be either spatially referenced or non-spatially referenced, depending on the source. If the source is a cadastral database or any other similar source containing individual building valuations, the dataset is spatially referenced. On the other hand, if the dataset contains generic values issued by the local chamber of construction or similar body for the purpose of estimating construction taxes and/or consulting or construction fees, the dataset is non-spatial. One of the “propositions” of this dissertation relates to the necessary distinction between the sources of the vulnerability damage ratios. The vulnerability damage data is non-spatial in the case of regular buildings, as the source of the data is historical records from previous earthquakes and possibly even from a different urban area. In the case of essential buildings, however, their vulnerability ratios are spatially referenced since these are surveyed individually. Essential buildings are studied in detail as they are key in the rescue and relief phases of the disaster management cycle and therefore these should be dealt with individually.

The data integration stage consists of the combination of datasets by means of table calculations and overlays (for an insight into the data integration steps, refer to Figures 5.3 and 5.4). Five final outputs are generated: the population risk, the building risk as well as both of these expressed in financial terms plus a risk figure which combines the previous two into a single figure. All these figures are presented as absolute figures as well as relative to

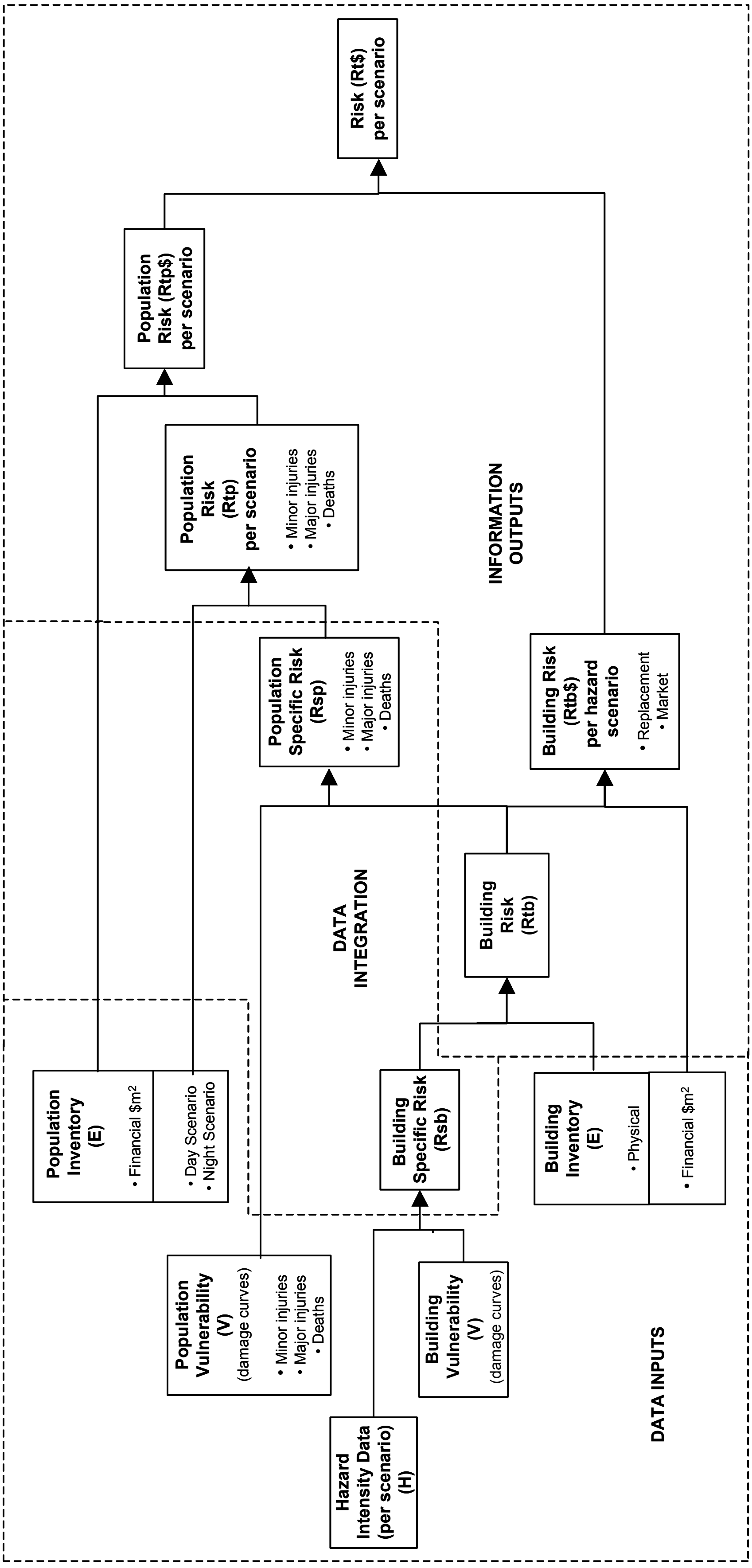

Figure 5.1: Risk Assessment Conceptual Model

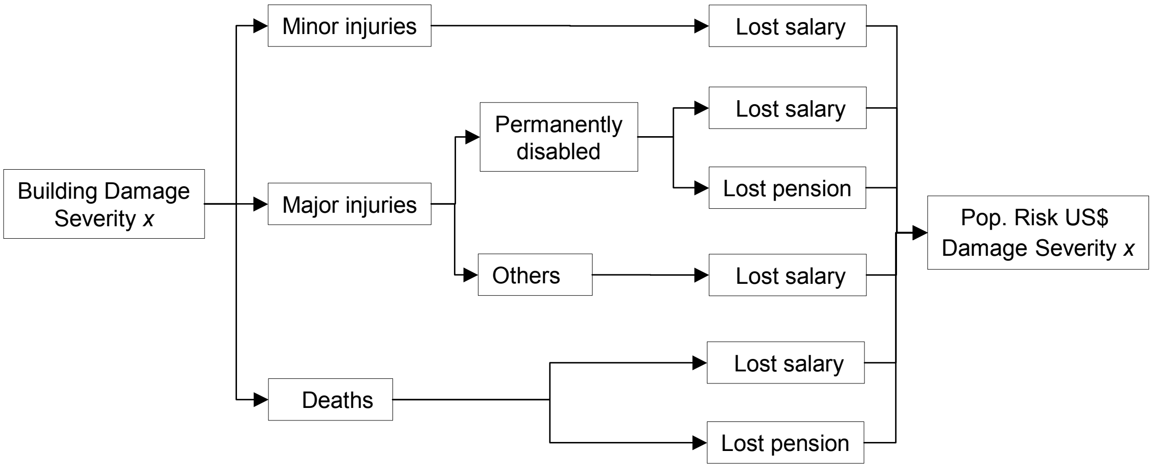

Figure 5.2: Flowchart of Population Risk Estimation per Damage Severity Class

the probability (return period). These five datasets constitute inputs for a cost-benefit analysis of mitigation strategies.

The building risk is expressed as the number of buildings (and total building area) in each damage severity class (none, very low, low, medium, high, very high), where the severity class is a reclassification of the percentage of expected damage. A threshold is set to identify the severity at which demolition is necessary, as beyond a certain degree of damage, repairs are no longer either economically or technically feasible. The damage severity class gives an insight into the magnitude of not only the rescue and relief necessary but also of temporary accommodation requirements (for further discussion on the application of the various components of the risk assessment, refer to Chapter Eight). For example, the classification allows the identification of the areas where deaths are likely, and these are associated with the severity class “very high”. Similarly, it is considered that people in need of temporary accommodation are those not associated with either of the severity classes “none” and “very low”. This classification makes it possible to calculate the duration of the victim’s displacement. The victims whose buildings are under classes “high” and “very high” will be displaced for longer periods of time as these buildings will probably be demolished and rebuilt. Conversely, the residents of buildings that suffered “low” damage, and that can therefore be repaired rapidly, will require only brief periods of temporary accommodation. Finally, the percentage of building damage is converted into financial losses expressed as replacement value.

The population risk is calculated on the basis of the building severity class (the higher the building damage, the higher the casualties). It is expressed as the number of people in each injury level (minor injuries, major injuries and deaths). The three-level classification allows emergency planners to prepare for and mitigate against a disaster. This breakdown is particularly useful to assess whether the local health facilities can cope, or whether pooling of resources across a wider area is necessary. On the other hand, the flat casualty figure (the sum of these three classes), is only useful in the context of regional planning as it enables the comparison between the levels of risk of urban areas within a region. To assess population risk in financial terms, lost earnings are computed for each injury class (refer to Figure 5.2). For deaths, the lost salary as well as lost pension are calculated based on: the average age, the retirement age, the life expectancy, monthly income, inflation rates and the last salary to pension ratio. For major injuries, a distinction is made between "permanently disabled" and "temporarily disabled" persons. For those permanently disabled, the same approach as employed to estimate losses to deaths is used. For those who suffer major injuries but are not permanently disabled, as well as for those with minor injuries, the salary equivalent to the number of days of leave is calculated.

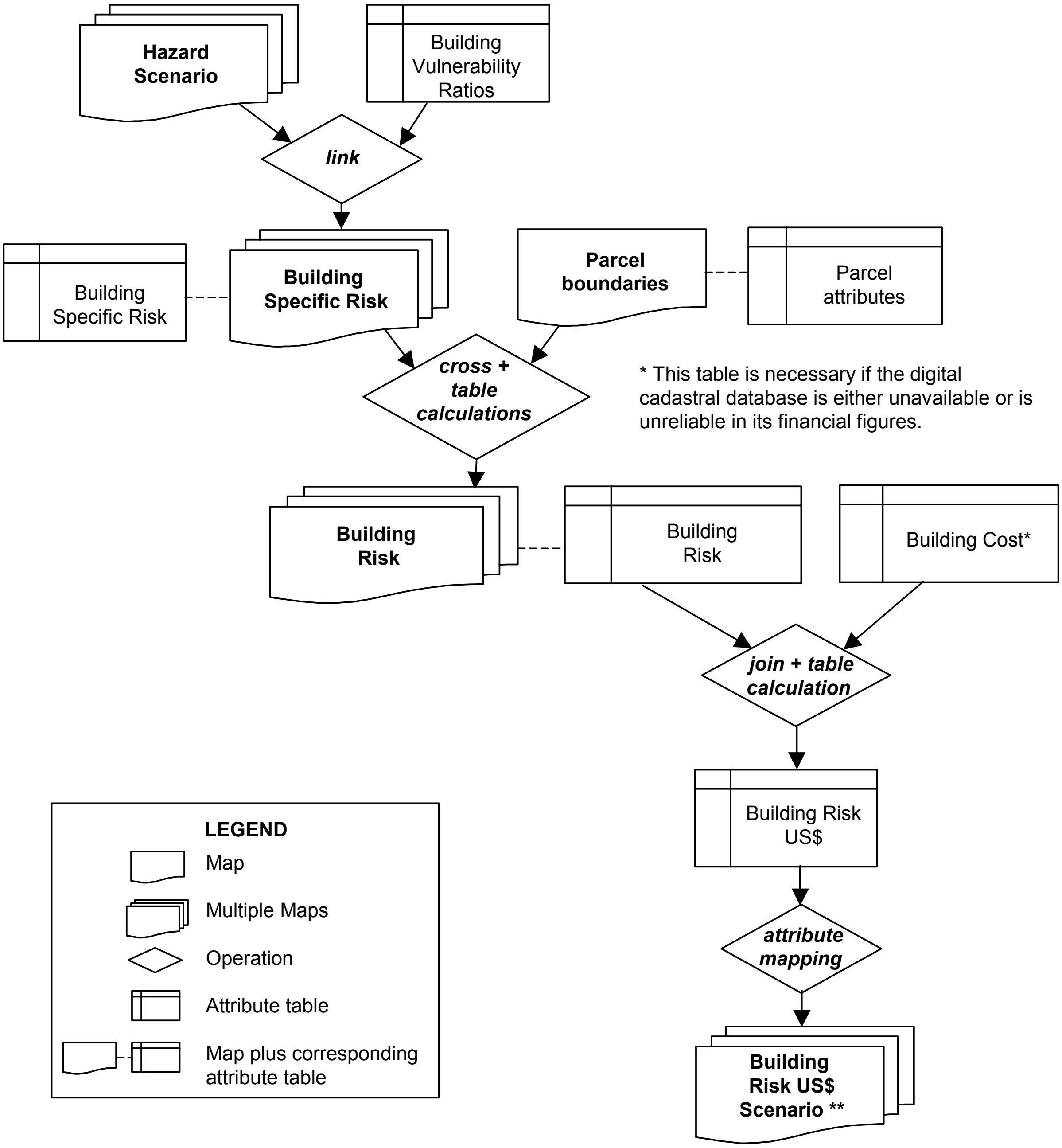

Figure 5.3: Flowchart of Data Integration Leading to Building Risk Assessment

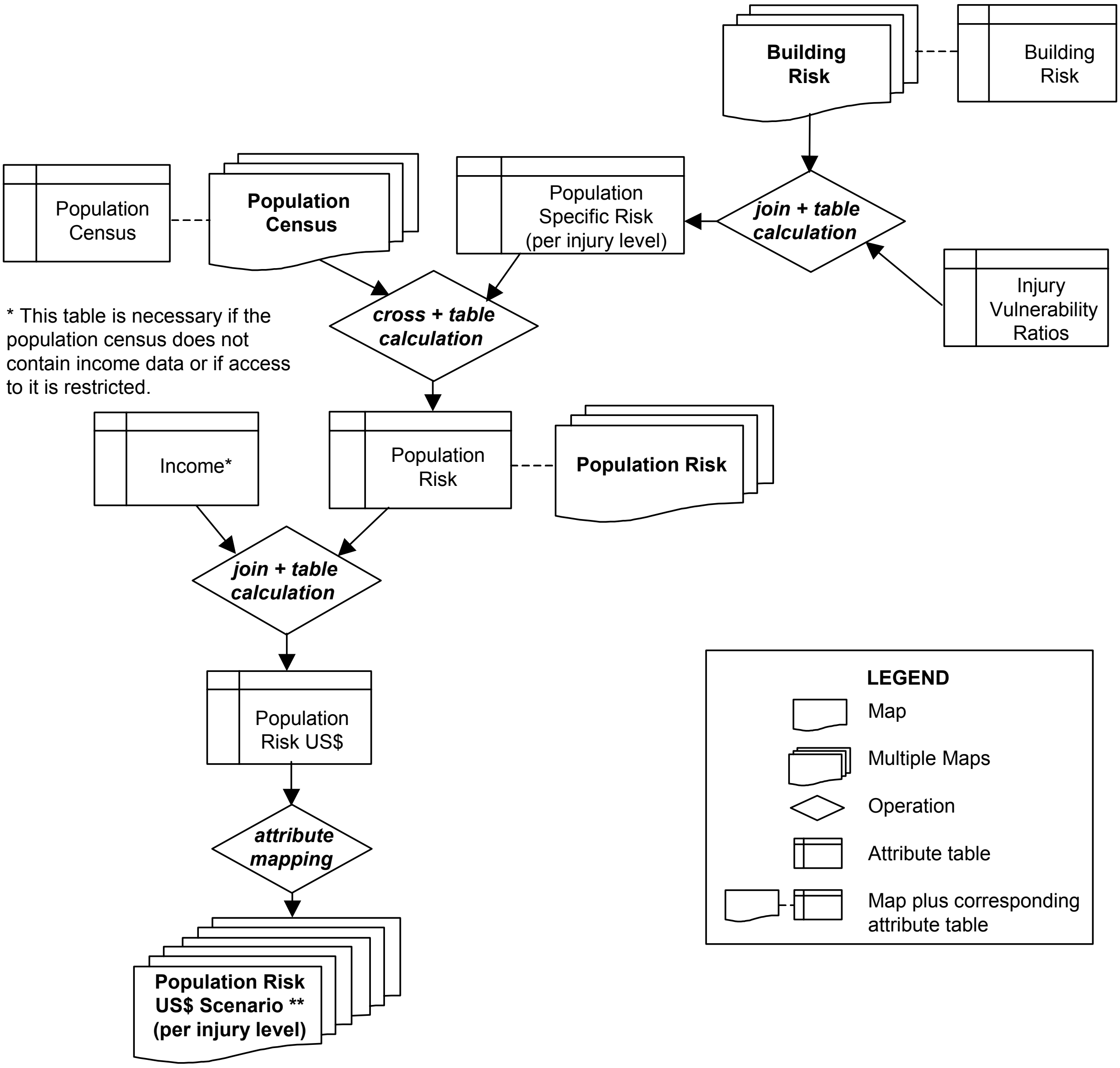

Figure 5.4: Flowchart of Data Integration Leading to Population Risk Assessment

5.2 INPUT REQUIREMENTS

The data requirements for assessing risk can be grouped into five categories (see Table 5.1).

To produce a specific risk zonation, a map of Modified Mercalli Intensity (MMI) values is required, since most of the vulnerability (damage) data is produced on the basis of this classification. As discussed in Chapter Three, whenever an MMI map is not readily available, it can be produced on the basis of a peak ground acceleration (PGA) map – although to ensure more accurate results, it should be calibrated according to soil types and topographic characteristics. In other words, in cases where the MMI values map is unavailable, three maps can be used to derive the MMI map: a PGA map, a soil types map and a topographic map. In the case of Cartago, an MMI map has been produced at a scale of 1:200,000 by Morales and Aguilar (1993), a pair of leading scientists from the School of Geology of the University of Costa Rica. Alternatively, a PGA map developed by Flores and Schmidt (2000) and a soil types map developed by the School of Geology (Flores and Chacón 1996) are both available at the larger scale of 1:50,000, while topographic sheets are available at 1:10,000. To achieve reliable results in the urban specific risk assessment, a map produced on the basis of a micro-zonation study (i.e. 1:25,000) is needed. Consequently, it can be concluded that in the case of Cartago, the hazard-related data available is somewhat unsuitable for conducting a study of this nature.

Requirements	**Availability** (Case Study: Cartago)
Hazard zonation	
MMI values	MMI map developed by Morales and Aguilar (1993) from the School of Geology at the University of Costa Rica
Building inventory	
Structural type	Not available in digital form (only available in individual paper files)
No. of floors	Not available in digital form (only available in individual paper files)
Land-use	IGN 1:10,000 series year 1991
Age of construction	Not available in digital form (only available in individual paper files)
Population	
Age group	National population census
Commuting patterns	Not available
Vulnerability	
Damage curves	Percentage of expected damage (Sauter and Shah 1978)
Risk	
Salary	Average monthly income, retirement age, pension to last salary relationship
Cost of construction	Metre square cost of new construction issued by the Board of Engineers and Architects of Costa Rica

Table 5.1: Summary of Input Data Required

Structural type, number of floors and land-use are the key data that the building inventory should contain. The land-use map allows the classification of buildings according to their level of importance during the post-disaster response phase. Moreover, in case there is no information related to the day population densities, the land-use map, together with data from the population census, is a crucial input for deriving this map.

The structural type classification of the inventory should be consistent with the classification used in the vulnerability (damage curves) study (in the Cartago case, the classification developed by Sauter and Shah (1978)). The number of floors in a building should be collected based on whole numbers rather than according to the classification made in the vulnerability (damage curves) study, the reason being that this data is relevant for other purposes as well. In the case of buildings with non-average floor heights, the approximate building height should be collected as well. The age of construction should be, in theory, available in whole years, to allow the calculation of a depreciation value (market value). It can later be classified according to the vulnerability study in case this highlights important benchmarks related to the implementation of building codes or other building regulation enforcement. In the case of Cartago, for example, the most recent building code was implemented nationwide in 1987. A class grouping all buildings of a given structural type and constructed between 1987 and 2002 can be used in the vulnerability assessment to yield more accurate results in the risk assessment.

The night population densities are easily derived (at census tract level) from census data since the basic unit is the household and the percentage of overnight workers is minimal (in most cities usually less than 2%). The day population densities can be very accurately calculated in cases where the population census is complemented by attribute data on the number of students and staff of every educational and health facility and a “business census”, which typically contains information about the line of work and number of staff in commercial and industrial establishments. In the case of Cartago, the business census is unavailable and therefore the census data along with a detailed land-use map provide an alternative for generating a daytime population density map. The number of persons per age group is key to the calculation of the day population densities, as different age groups carry out different activities throughout the day. For example, in the case of Cartago a questionnaire was used to identify the mobility patterns and it was concluded that those remaining in residential areas during the day are typically all those below the age of 4, most of those above the age of 60, plus a fraction of those between the ages of 19 and 60. Similarly, if data on the number of students per educational facility is not available, the age group data can be used to estimate the densities within the educational areas. In the case of Costa Rica, the census data identifies in each census tract the number of persons that attend school in the following age groups: ages 5 to 6 (kindergarten students), ages 7 to 12 (primary school students), ages 13 to 19 (secondary school students), 20 to 29 and above 30 (higher education students).

Additionally, national or regional centres must be identified and dealt with somewhat separately. These types of centres are unique in the sense that they house people that reside somewhere else. Typical examples include specialised hospitals, hotels, jails and universities. In the case of Cartago, for example, the Technological Institute of Costa Rica (ITCR) attracts 7,500 students, most being non-Cartago residents. The population that attends these centres must be identified and the figure must be assigned specifically to the corresponding polygon and not reached by making inferences based on the census data. Figure 5.3 illustrates the operations used for estimating the day population densities.

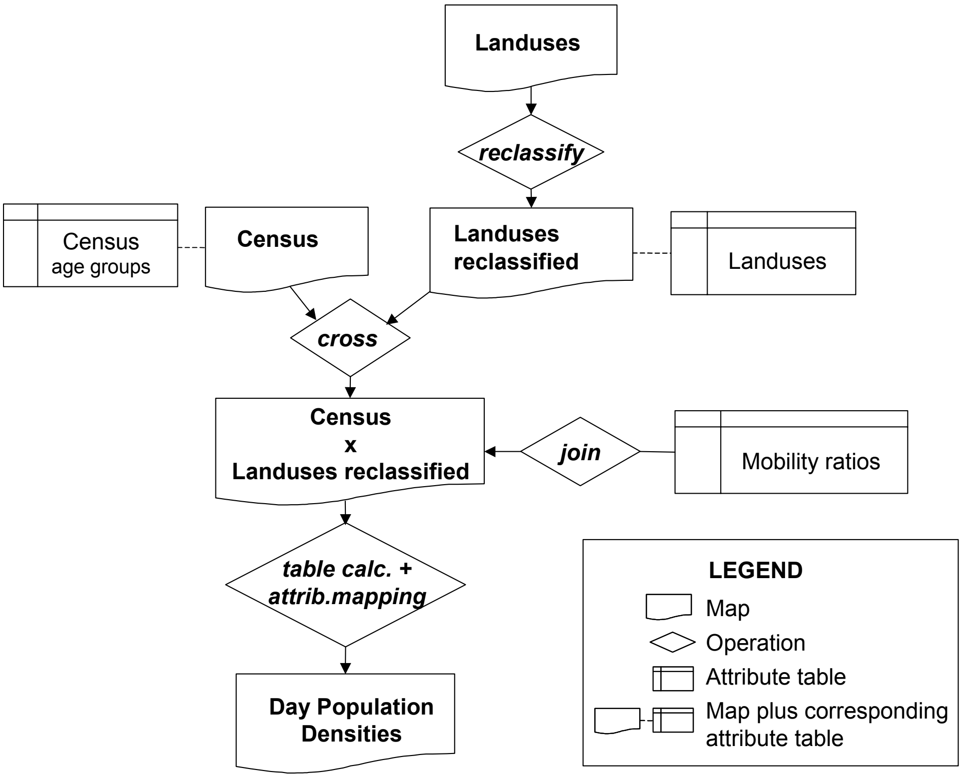

Figure 5.5: Flowchart of Day Population Modelling

For calculating the cost of buildings, the cost of construction per square metre, as well as the approximate height of floors, is necessary. Whenever buildings have floors with highly irregular heights (i.e. churches, roofed sports facilities), the standard cost per square metre of construction must be calibrated on the basis of floor height. In cases where the market value of the buildings cannot be extracted from cadastral files, the age of construction along with the maintenance level of the building can be used to calculate the depreciation of the building over time on the basis of the cost of construction per square metre.

For estimating the lost human capital, the average age of the population, the retirement age, the monthly salaries and the ratio of pension to last salary are necessary.

5.3 DATA CAPTURE

A data capture methodology has been designed with the objective of producing a spatial database containing relevant building attributes for the purpose of earthquake risk assessment. The reason why this methodology is necessary lies in the nature of cadastral databases. In most cases, cadastral databases are designed solely for registration and taxation purposes and therefore the classification of buildings contained in these databases tends to be useless for earthquake risk assessment.

Figure 5.6 illustrates the proposed methodology for creating a building inventory spatial database.

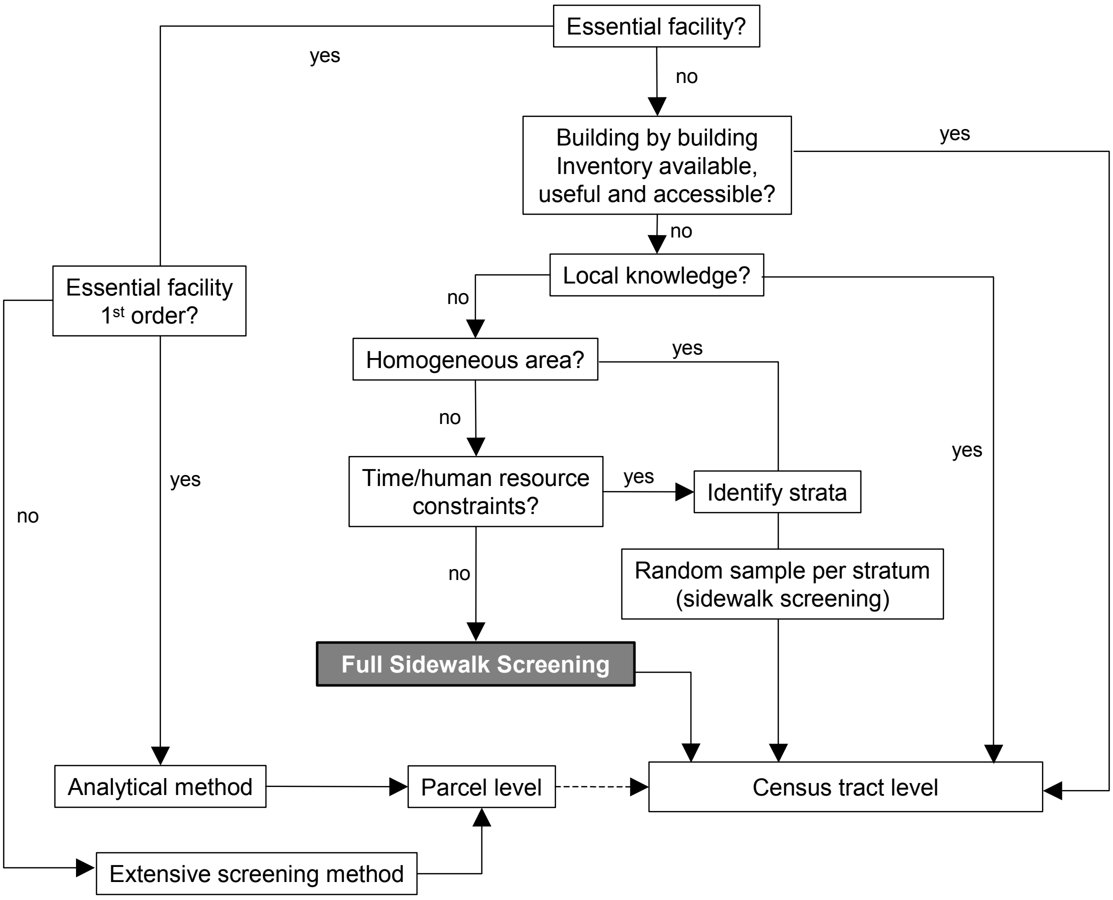

Figure 5.6: Flowchart of Building Inventory Data Capture Methodology

5.3.1 Classification of Buildings

The first step involves classifying land-uses according to their strategic importance. A classification is necessary as it is not economically feasible to conduct a thorough analysis of the seismic response of all buildings. It is, however, more than a financial issue as in many cases the technical staff that would be required for such an assessment to be carried out within a reasonable time frame are unavailable in the numbers required. Since rescue and relief are crucial in keeping casualties to minimum levels, a sensible solution is to classify buildings in three classes (i.e. essential primary, essential secondary and regular) and a data capture method can be applied to each category.

Essential buildings can be described as those that a city cannot afford to lose in a disaster. Hospitals and clinics, the fire brigade, police headquarters as well as the town hall are such buildings, which are vital not just for emergency rescue and relief but also for maintaining public order, as looting is a common problem following a disaster. One could view these land-uses as “essential primary”. Schools, community centres and churches are also important since following a disaster these buildings tend to be used by emergency officials for housing the displaced population. These land-uses could be classified as "essential secondary". Other types of land-uses that require special consideration include housing for the elderly and rehabilitation centres.

	Data Collection Method		
Importance	Analytical/ Mathematical	Extensive Screening	Sidewalk Screening
Regular			√
Essential primary	√		
Essential secondary		√	

Table 5.2: Capture Methods

The mathematical analysis of structural behaviour offers the most reliable results for the purpose of vulnerability assessment. On the negative side, it requires highly qualified staff (i.e. structural engineering specialists) and is extremely time-consuming. Moreover, computer simulation of the structural response is dependent upon the availability of construction plans (blueprints). Furthermore, if doubt exists related to compliance with the approved construction plans, laboratory testing of building materials (e.g. concrete *fc*) in a specialised laboratory might be necessary. Extensive screening is obviously less reliable but it is more time-efficient and cost-efficient. Essential buildings could therefore be subdivided into two categories: "first-order" buildings could be assessed using mathematical modelling, while "second-order" buildings could be assessed by extensive screening (refer to Table 5.2).

There are various ways of carrying out ground surveys for non-essential buildings. A common method is the "rapid sidewalk screening of buildings", a method which is widely used in the USA. This method involves the collection of information based on a survey sheet agreed *a priori*. In its most simplified form, this method requires approximately a 10-minute inspection per building. In the case of Cartago, for example, surveying the housing building stock would involve around 5,000 hours. This method has obvious limitations, such as the time required and the uncertainty posed by inferences based on analysing only the building façade. On the other hand, this method is realistic in the sense that no written consent from the owner is required as it does not involve entering the property.

The alternative method proposed here for capturing data on non-essential facilities for building inventory generation involves combining remote sensing and ground video images produced from a moving vehicle.

Large Format Vertical **Small Format Oblique**

Figure 5.7: City Centre of Cartago: Mixed Land-Uses and Mixed Use of Building Materials and Structural Types

Figure 5.8: Industrial Estate in Cartago: Single Land-Use and Homogeneous Building Materials and Structural Type (Pre-Cast Reinforced Concrete)

Figure 5.9: Low-Income Housing in Cartago: Single Land-Use and Homogeneous Building Materials and Structural Type (Reinforced Masonry)

5.3.2 Remote Sensing

The generation of a building inventory can be achieved using remotely sensed imagery such as high-resolution satellite imagery (e.g. IKONOS) and aerial photographs (either vertical or oblique). The analysis of heights, textures, patterns, tones, size and shadows can be combined with local knowledge to identify homogeneously built areas. These areas are easily identified in survey photographs typically produced by national survey authorities and which tend to be available at scales of at least 1:20,000. The most common examples of homogeneous areas are industrial and housing estates (see Figures 5.8 and 5.9). In cases where homogeneous areas are identified, the size of the ground survey can be decreased as, based on the analysis of a single building, generalisations can be made about the characteristics of these homogeneous areas without hampering the accuracy of the results.

It must be noted, however, that the resolution of conventional aerial survey photographs still remains higher than that of commercially available satellite imagery such as IKONOS and QUICKBIRD. However, since the resolution of satellite imagery continues to increase at a rapid pace and the prices per scene and minimum purchase orders continue to decrease due to increased competition, satellite imagery might soon become the preferred source of remotely sensed imagery used in urban applications.

Another aspect to consider is that the production of conventional vertical survey photographs requires not only dedicated aircraft carrying highly sophisticated camera systems but also highly trained personnel. This therefore means that often missions cannot be carried out at short notice. In cases where recent conventional survey photographs are not readily available, simple options such as small format oblique photography from the window of a small aircraft are worth considering. Such a technique uses relatively inexpensive “off-the-shelf” equipment and can be rapid to implement. Moreover, if the photographs are needed solely for the purpose of delineating homogeneous areas, contracting conventional photographic surveys is probably excluded from a cost-benefit point of view.

5.3.3 Ground Data Capture

In the first instance, remote sensing (i.e. photographs or satellite imagery) is used to identify homogeneously built areas in which a single sampled building allows one to infer the characteristics of the whole area. Video images produced from a moving vehicle on the ground allow one to make inferences about the characteristics of buildings. This technique could have a drawback in the sense that large vehicles parked along the sidewalk might block the view of the building’s façade – although making the recordings early in the morning can minimise this.

A global positioning system (GPS) and digital video can be used in a first stage to produce an image of a building’s façade of known location. In a second stage, the required attributes are extracted from the analysis of the image.

This data capture method offers six main advantages:

- The recording is multi-functional
- The recording process is not too time-consuming
- The recording process requires little technical expertise
- The costs involved are within the reach of municipalities in developing countries
- The location (*x,y* coordinates) of every image can be established in an automated way

Since the classification and other interpretation issues can be decided *a posteriori*, the recording is multi-functional in the sense that it can be used for a variety of purposes and not just for urban earthquake risk assessment. For example, to impose fines on illegal construction or advertisements, local governments often have to trace the year in which a particular illegal act took place. This is necessary as typically in these cases the enforcement of a law or regulation lapses after a given period of time. The video recordings would therefore be an important source of information, especially if they are carried out periodically.

Figure 5.10: Example of Portable Equipment

Citywide coverage can be achieved in a few days with a single driver, one vehicle, one digital camera and a GPS unit (refer to Figure 5.10). Preferably, two digital video cameras should be used as this allows the recording of building façades from both sidewalks at the same time. The GPS is used to provide the location in *x,y* coordinates at a given time. Most GPS units are able to internally record positions in a “track log” at intervals of 1 second.

The coverage of the image depends on two factors:

- The angular view of the camera system (which in turn depends upon its detector array and lens focal length)
- The distance from the camera (vehicle's window) to the property line (see Figure 5.11)

Careful consideration should be given to this issue as in cases where the sidewalk is narrow the coverage will be limited. In the case of Cartago, given a minimum distance from camera to property line of around 4 m and a given lens angle of view, maximum vehicle speed should be in the order of 17 km/h.

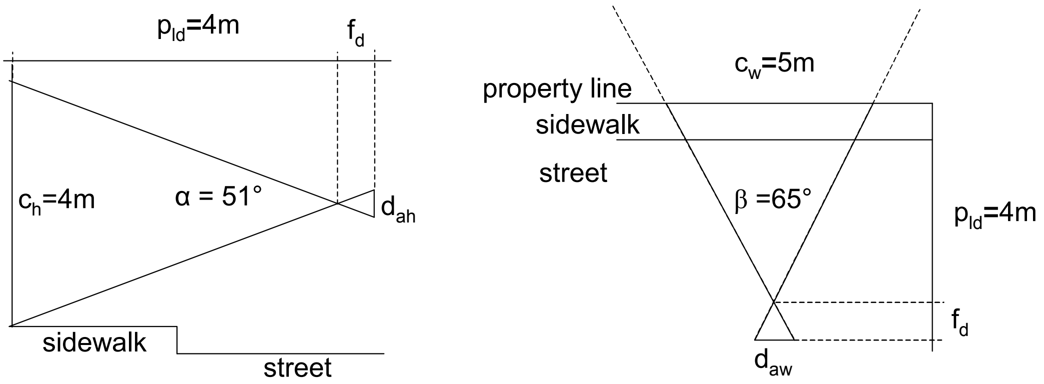

Figure 5.11: Coverage Calculation (elevation on left; plan on right)
(dimensions indicated are approximate)

$$c_w = 2 \cdot p_{ld} \cdot \mathrm{Tan}(\tfrac{1}{2}\beta) \qquad c_w = p_{ld} \cdot d_{aw} / f_d$$

$$c_h = 2 \cdot p_{ld} \cdot \mathrm{Tan}(\tfrac{1}{2}\alpha) \qquad c_h = p_{ld} \cdot d_{ah} / f_d$$

Where:

c_w = coverage width
c_h = coverage height
d_{aw} = detector array width
α = vertical angle of view
d_{ah} = detector array height
f_d = focal distance
p_{ld} = property line distance
β = horizontal angle of view

For the GPS-derived coordinates, most budget (handheld) GPS units are nowadays capable of providing positional accuracy to within 6 to 12 m (Garmin 2000).

However, it is possible to improve upon this positional accuracy yet further by employing differential GPS techniques. This may be achieved either in real-time mode (where the GPS also receives a broadcast "correction" signal) or during post-processing (where data from a reference station is utilised). Unfortunately, such techniques may be beyond the means of an untrained operator.

Another important advantage of the GPS is that provided that there are four or more satellites in view, approximate altitude can be recorded, and in cases where no contour mapping is available, this could be used as the source for creating digital elevation models (DEMs). However, the altitude measurement from simple GPS receivers is considerably less accurate than the planimetric accuracy.

Since essential facilities and homogeneous areas are surveyed by using different methods and since only areas that contain buildings are in need of video recording, it is necessary to filter out some sections of the road from the ground video capture phase. The sections of road that should be excluded are those that lie next to vacant areas, essential facilities or homogeneous areas. To obtain the route map, the road map is first buffered and then overlaid with three other maps (i.e. essential, homogenous and vacant). This filtering is useful because it cuts down not only on the time needed to record the video images but also on the time required for interpreting them. Figure 5.12 illustrates the portions of the initial route that will require interpretation.

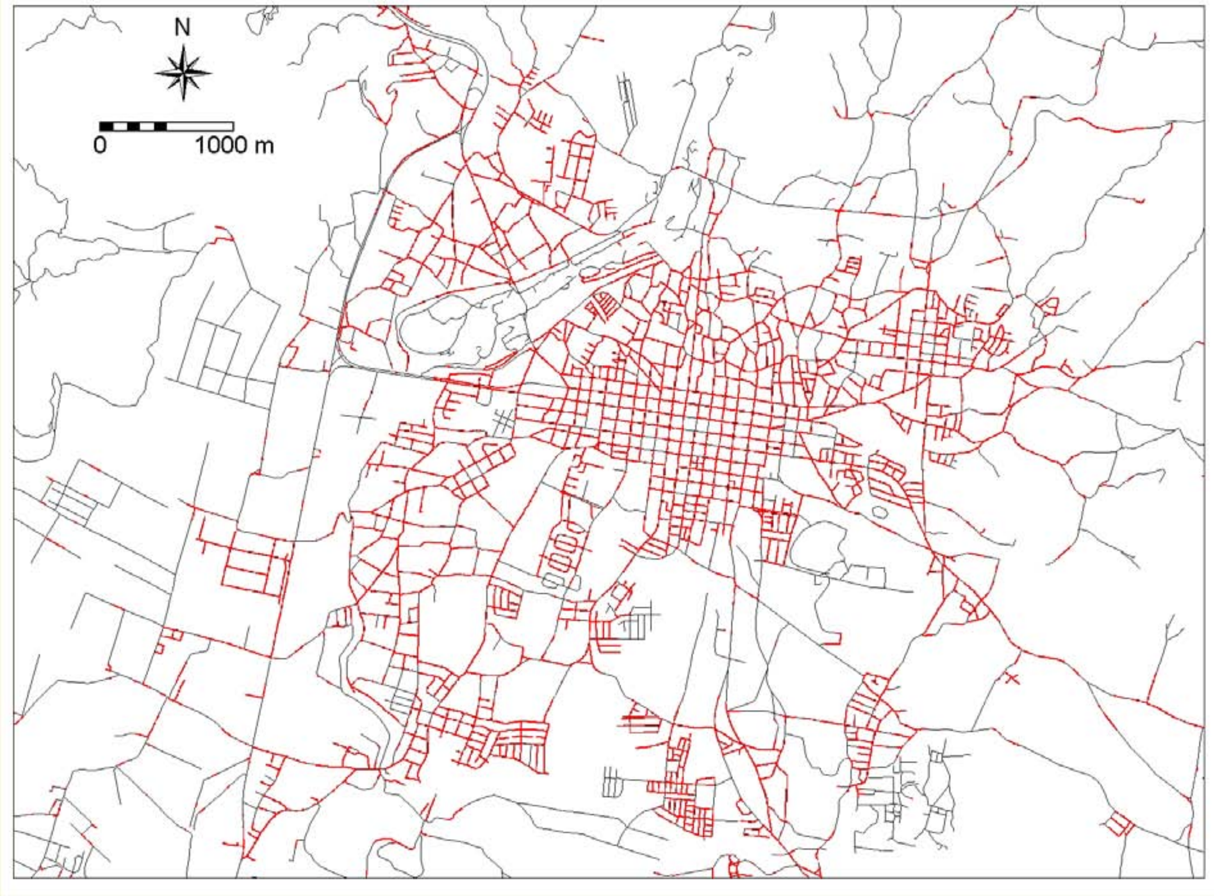

Figure 5.12: Limitation of Extent of Video Image Interpretation

5.3.4 Data Manipulation

It is important to note the 1:N (one to many) entity relationship that occurs, since it is possible that more than one image is associated with one location (two video cameras, one each (window) side, recording at the same time). Moreover, the vehicle could be stationary due to traffic jams or traffic lights so there could also be many images associated with each window side for one location. The relationships are therefore 1:N, where membership of "Location" in the "contains" relationship is obligatory, while membership of both "Image left window" and "Image right window" is non-obligatory (refer to Figure 5.13). This characteristic is very important, as it leads one to conclude that the only attribute that could be distinctive about the images is the date (date/time) of recording. This is important from the point of view of selecting an attribute that could be used as an identifier, but also important at a later stage when optimisation is needed in order to eliminate redundancies and duplicates from the database.

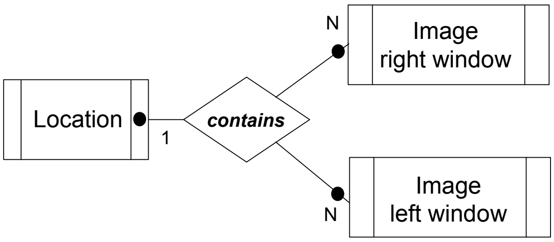

Figure 5.13: Entity-Relationship Model

The interpretation is carried out after the recording has been made and therefore, depending on the financial resources and also on the manpower available, there is the option of interpreting all the images or sampling a given number of random locations within the non-homogeneous built-up areas (see separate section on sampling).

Regarding the video images, digital video cameras nowadays offer single mode (video only) or dual mode (video plus digital stills). Even when only single mode cameras are available, individual still images (i.e. JPG, TIFF) can be obtained from the video by means of digital still capturing software packages. Moreover, another even lower-cost alternative is possible by using digital still cameras, provided that the camera offers continuous shooting mode to capture an image (i.e. JPG, TIFF). However, inexpensive digital still cameras rarely have the capability to record images at sufficiently rapid intervals or to store sufficiently large numbers of images.

The method of linking up the GPS position data to the video images is surprisingly simple and reliable, provided the internal clock information of both devices is used (refer to Figure 5.14). This is very convenient as it makes it unnecessary to real-time link the GPS and the video camera to a laptop computer during the field ground capture phase. By resetting the clock of the video to match the clock information values (i.e. year/month/day/hour/minute/second) of the GPS device, it is possible to easily establish where a given image was captured.

To ensure that the individual images (i.e. JPG, TIFF) can be hyper-linked to the GPS points' attribute table in an automated manner (refer to Figure 5.15), the images must be named after the video's time code. For the Cartago case study, video capture software capable of naming individual files after the time code of the video (i.e. scene'20010921 08.08.30.JPG) was purchased (refer to Figure 5.15). Whenever two video cameras are used at the same time (one on each side of the vehicle), the time code must make reference to the window side (left/right). To identify the window side, the filename is modified by adding an extra character (i.e. Rscene'20010921 08.08.30.JPG).

The GPS data (i.e. x, y, date, time, leg length, speed, heading) is easily downloaded into a computer and a table can be created to both display and manipulate the data. Some "macros" are necessary to:

- Combine the date/time columns into a single column
- Add the extension name of the file (i.e. ".JPG")
- Add any prefix necessary to match the time-code format used by the video capture software (i.e. "scene")
- Strip down any unwanted characters

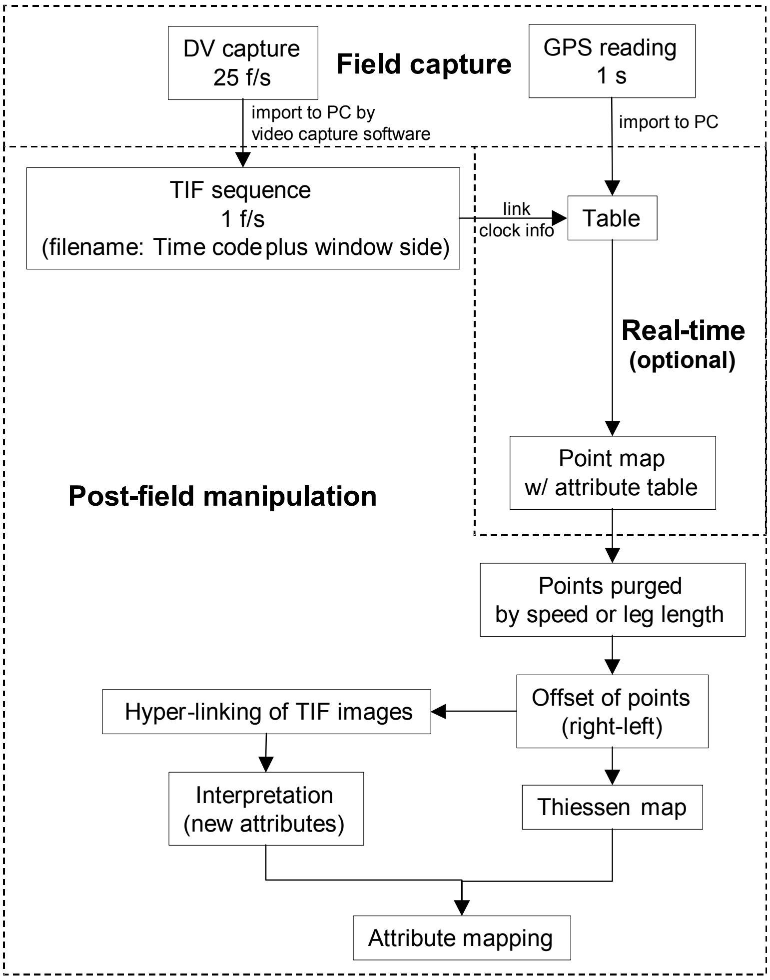

Figure 5.14: Use of GPS and Digital Video for Building Inventory Generation
(adapted from Montoya (2002))

scene'20010921 08.08.44.JPG scene'20010921 08.08.43.JPG scene'20010921 08.08.42.JPG

scene'20010921 08.08.41.JPG scene'20010921 08.08.40.JPG scene'20010921 08.08.39.JPG

scene'20010921 08.08.37.JPG scene'20010921 08.08.35.JPG scene'20010921 08.08.34.JPG

scene'20010933 08.08.29.JPG scene'20010921 08.08.32.JPG scene'20010921 08.08.31.JPG

scene'20010921 08.08.30.JPG scene'20010921 08.08.29.JPG scene'20010921 08.08.28.JPG

Figure 5.15: Series of Captured Images from Digital Video

Amongst many functionalities, most geographical information system software packages are able to use the *x,y* columns of the table to produce a point map, which opens up a wide range of possibilities for computer-based spatial analysis.

The analysis or interpretation of the images provides new attributes that then lead to an expansion of the GPS points' attribute table. In the Costa Rican case, leading structural engineers have indicated that due to the building stock characteristics (Chen, Chen et al. 2001; Sauter and Shah 1978) the structural type and the age of construction are enough to assess seismic building vulnerability. In other countries, however, other attributes that might be necessary and could be extracted from the image include building height and configurational asymmetries, to name the most common ones.

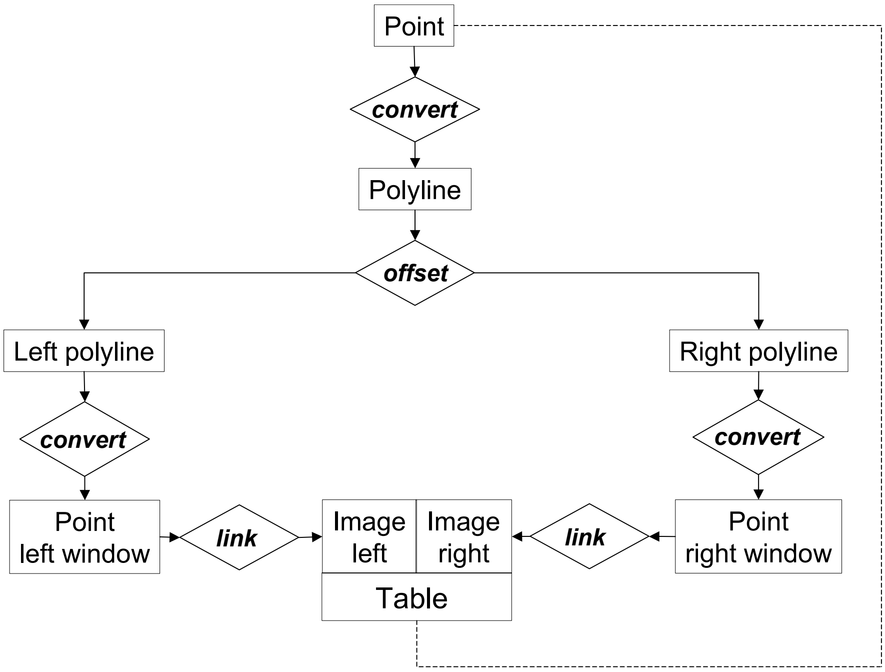

Figure 5.16: Flowchart of Point Offset Procedure for Thiessen Map Generation

In cases where the parcel or building boundaries are available in digital form, the attributes obtained from the interpretation of the still images can be assigned directly to the corresponding polygon. When no digital parcel or building boundaries are available, however, a possible alternative is to use the GPS points to generate Thiessen polygons. To obtain these Thiessen polygons, the GPS points are first converted into a polyline to allow an offset procedure to be carried out according to the average road width. Once the polyline has been offset both to its right and to its left, the two polylines are converted to points (refer to Figure 5.16) and these are next interpolated to obtain the Thiessen polygons. These Thiessen polygons are used for spatial analysis until the final stages when data is aggregated to the census tract level before it is supplied to decision-makers. It must be noted that preferably parcel boundaries should be generated from photogrammetric sources and the generation of Thiessen polygons should be seen as a last resort when no digital parcel boundaries are available.

5.4 STRATIFIED SAMPLING

Through ground video recording, it is possible to obtain video images of the entire city. Sampling should be considered carefully, as in a relatively small city like Cartago, with a population of less than 150,000, the total number of images generated by the digital video is approximately 20,000. There might be cases when, given the cost, time and availability of interpreters, a decision is made not to interpret all the images. This section explores the use of random sampling techniques to produce a building inventory. Figure 5.17 illustrates the steps required in a sampling process.

Random sampling is a type of probability-based sampling. In this technique, every building in the building stock has a known, non-zero probability of being included in the sample. The advantage of probability-based sampling over other types of sampling methods is that it allows the quality of the estimation and the estimation method to be measured.

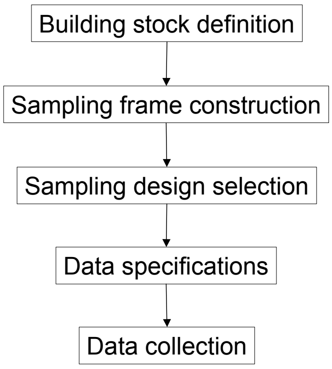

Figure 5.17: Steps in the Building Sampling Process

A sampling survey is composed of a sample design (which images are to be sampled and how the data will be used for making inferences) and a survey instrument (how the measurements are to be made, what is to be observed). To achieve success in a survey, both these aspects must be carefully constructed and implemented. The sample design deals with both the sampling plan (the way in which the sample is selected) and the estimation procedure (the formulas that will allow the production of estimates and inferences).

The most commonly used sample is known as a “simple random sample”. The drawback of this sampling technique is that there is always the possibility that the images selected for the sample will be unrepresentative. In this section, a method that decreases the sampling error (the uncertainty that arises from working with a sample rather than with all the images) will be explored.

Unlike simple random sampling, stratified random sampling offers the advantage that the random sample is not left entirely to chance. Burt and Barber (1996) define a stratified random sample as that obtained by dividing the population into classes or strata, and then selecting a simple random sample from each.

Blalock (1979) considers that, in simple terms, stratified sampling can be applied to yield greater accuracy for the same cost or to involve less cost for the same accuracy. In developing countries where financial resources are scarce, stratified sampling therefore constitutes an interesting alternative. Trochim (2001) indicates that stratified random sampling has two major advantages:

- It ensures that one will be able to represent not only the overall population (in this case the images) but also the key subgroups of the population, especially small minority groups (in this case adobe mud-brick buildings, which have the highest vulnerability but occur less frequently).
- It generally has more statistical precision than simple random sampling. If the strata or groups are homogeneous, the variability within the strata is lower than the variability for the building stock as a whole.

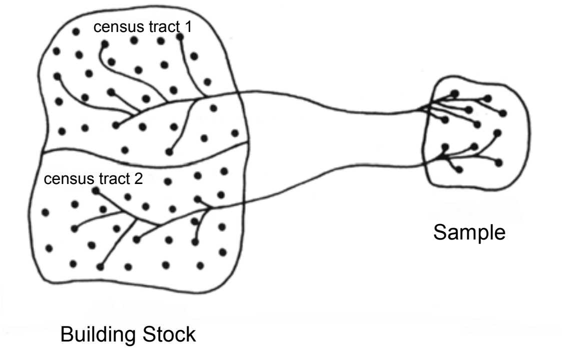

Figure 5.18: Conceptual Diagram of Stratified Random Sampling (adapted from Burt and Barber 1996)

The basic idea behind stratified random building sampling is illustrated in Figure 5.18. The urban area is divided into a set of strata before sampling takes place. The divisions must be both exhaustive and mutually exclusive. In other words, each image must appear in one and only one stratum. This type of sampling method is ideal for urban areas as in most cases some sort of spatial stratification already exists. Existing stratifications should be carefully analysed before being adopted, otherwise there is the danger that the stratified sampling will yield the same accuracy as a simple random sample. For example, in the case of Costa Rica, according to its National Statistics and Census Institute (INEC), a census tract is a unit consisting of between 40 and 60 houses of homogenous building characteristics (i.e. size, building material) and has a population that is also homogeneous in terms of its socio-economic characteristics. The census tract therefore constitutes an ideal stratum for conducting a stratified random sampling leading to a building inventory for seismic vulnerability determination. There is, however, a drawback in the sense that the census tract's boundaries are delimited based on the analysis of housing (and its occupants), while other land-uses are not taken into account.

Generally speaking, one should select a simple random sample in each census tract according to a chosen sampling fraction. One issue that must be carefully analysed relates to the sampling fraction, as there are two possible options. With proportional stratified random sampling the same sampling fraction is applied to all census tracts irrespective of their size (number of images). On the other hand, with disproportional stratified random sampling the sampling fractions applied to each census tract will differ. In disproportional stratified sampling different sampling fractions are used to manipulate the number of cases selected in order to improve still further the efficiency of the design.

To analyse the case of Cartago, the census tract map has been overlaid with the route map (refer to Figure 5.12) to generate statistics about the number of images per census tract. To analyse the whole of Cartago, a full interpretation would involve approximately 6,500 images. The mean number of images per census tract is 26, with values ranging from 1 to nearly 230 and a standard deviation of 19. Since the standard deviation is high, applying a proportional sampling fraction of one to five, for example, would translate into a minimum sample size of one image (since there are census tracts that only have one image) and a maximum sample size of 46. With proportional sampling, the total number of images to be interpreted would be approximately 1,300. The other option is to carry out a disproportional sampling – in other words to select an equal number of images from each census tract. With a disproportional sampling size of one to five of the mean number of images, the total number of images to be interpreted would be approximately 2,500 images.

5.5 CONCLUSIONS

It was concluded that given an earthquake hazard scenario, it is possible to model population and building risk based on the combination of widely available data (e.g. census data, land-use maps) together with data that can be produced rapidly, easily and inexpensively. Due to the high damage rates of older buildings, stratification based on a map of urban growth (produced from remotely-sensed data) should be used as a mechanism to achieve higher statistical precision.

Chapter Six: NATIONAL PLANNING POLICY AND LEGAL FRAMEWORK

This chapter analyses the legal framework in terms of both urban planning in general and disaster management. The objective is to identify the institutions and individuals involved, as well as the responsibilities and programmes or regulations currently available. The following chapter introduces the case of the city of Cartago in Costa Rica.

6.1 INTRODUCTION

The objective of this section is to present the strengths and weaknesses of the legal framework in the field of urban development and disaster mitigation. To carry out this type of analysis, the seven principles of good urban governance stated by the United Nations Development Programme (1997) provide an insight into individual goals that the framework as a whole should be able to achieve:

- **Sustainability** in all dimensions of urban development
- **Subsidiarity** of authority and resources to the closest appropriate level
- **Equity** of access to decision-making processes and the basic necessities of urban life
- **Efficiency** in the delivery of public services and promoting local economic development
- **Transparency** and **accountability** of decision-makers and all stakeholders
- **Civil engagement** and **citizenship**
- **Security** of individuals and their living environment

In Costa Rica, written accounts of urban development regulations can be traced back to regulations for founding cities in the reign of Charles V of Spain and more recently to Braulio Carrillo's laws of 1841. However, this section will focus on the current legal framework that regulates urban development and disaster mitigation. It is useful to start by identifying the stakeholders involved in this process according to the various levels of government (refer to Figure 6.1). At the national level, the main institutions involved are:

- The Parliament (*Asamblea Legislativa*)
- The Cabinet (*Poder Ejecutivo*)
- The National Housing and Urbanism Institute (INVU)
- The Federated Board of Engineers and Architects (CFIA)
- The National Cadastre
- The National Statistics and Census Institute (INEC)
- The National Insurance Institute (INS)
- The National Commission for the Prevention of Risks and Response to Emergencies (CNE)

- The Ministries of Housing and Human Settlements (MINVA), Health (MS), and Transportation (MOPT)
- The Constitutional Court (*Sala Cuarta*)
- Other important institutions include private or public banks

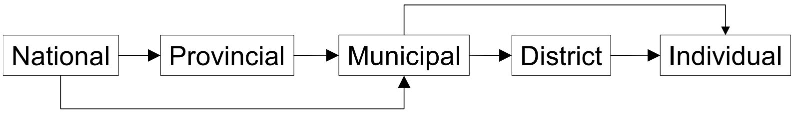

Figure 6.1: Levels of Decision-Making

Even though the country is divided into provinces, which in turn are divided into municipalities, the provincial governments have no significant task and therefore this level of government is often bypassed. Moreover, some ministries such as the Ministry of Health and the Ministry of Education have defined their own planning regions. This is obviously highly unsuitable from the point of view of data sharing and information networking. Similarly, the district level seems to exist only for the purpose of electing representatives to the district assemblies of political parties, as no planning is carried out at this level nor do regulations exist for this spatial unit. Strangely and contradictively, the district level is the smallest spatial unit at which the National Statistics and Census Institute (INEC) is willing to grant access to spatially referenced data.

At the local level, the institutions involved are the municipalities, non-government organisations, community-based organisations and individuals.

Next, a review will be carried out related to the roles of the various institutions involved in urban development and urban disaster management, according to the various laws. Figure 6.2 describes the relationships amongst the various stakeholders involved in the urban development process, which will be described in detail in the following sections.

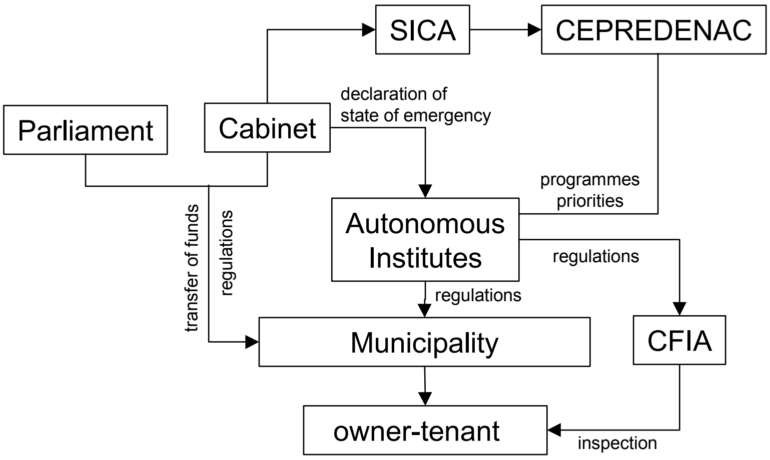

Figure 6.2: Stakeholders in the Regulation of the Construction Process

6.2 ORGANIC LAW OF THE NATIONAL HOUSING AND URBANISM INSTITUTE (INVU)

INVU was created in 1954 and its role includes supervising and encouraging planning, as well as providing housing. Despite its legal status as an “autonomous institute”, its board of directors is composed of a member from the Ministry of Labour plus four Cabinet appointees, which raises a question over its level of autonomy.

Apart from its role in overseeing the urbanisation process (see Section 6.3 for details), this institution is also in charge of providing the homeless (particularly the low-income) with adequate shelter. INVU also offers savings programmes geared towards housing construction or purchase, which have proved very popular with middle-income groups. Another important INVU objective is to stimulate those industries that could in some way help to solve the housing and urban problems in general.

The legal framework allows both INVU and the Ministry of Health to carry out gradual elimination of those houses and other types of constructions that are considered dangerous or unsanitary. Interestingly, these two institutions are allowed to carry out this duty either jointly or separately.

Unfortunately, one of the major challenges facing INVU relates to its financial situation. The institution is financed through the national budget but its financial situation can be described as precarious. Recently, INVU has started charging a fee of 1% on the cost of urbanisation projects (sites and services only), which could help to improve matters.

6.3 URBAN PLANNING LAW

The Urban Planning Law has been revised on a number of occasions since it was first issued in 1968. This document discusses the purpose of planning and the mechanisms by which it should be carried out in Costa Rica. In this document planning is seen as the activity that aims to achieve a) an orderly expansion of urban centres, b) equilibrium between urban and rural development through an adequate distribution of population and economic activities, c) an efficient development of urban areas to make best use of natural and human resources and d) an adequate investment in public works. INVU plays an important role in the field of urban disaster management since its responsibilities include:

- Producing, revising and updating a National Urban Development Plan
- Coordinating private and public projects directly linked to the plan
- Advisory services to municipalities and other institutions carrying out planning at a local level
- Enforcing urban development laws
- Guiding and controlling the urban development process

In terms of guiding and controlling the urban development process, INVU has several important duties and also the right to step in if necessary. Firstly, all strategic municipal development plans must be approved by INVU prior to their adoption at the local level. Secondly, all neighbourhood site plans, including land subdivision plans, must be approved by INVU following preliminary approval by the municipality. Thirdly, INVU has the right to order the suspension of construction work in cases where the municipality has failed to enforce regulations. If necessary, INVU has the right to immediate police support to ensure compliance with regulations.

INVU must prepare, revise and update a National Urban Development Plan. Strangely, this policy document must be approved by the Cabinet rather than by Parliament. It must be forwarded to the municipalities as well as any other relevant institutions.

One of the objectives of the National Urban Development Plan is to provide advice to Parliament and other national, regional or local government institutions on the prioritisation of the various projects or issues. At a local level, specific regulations that INVU encourages municipalities to produce, enforce and update include a strategic municipal development plan known as *plan regulador*, and zonation regulations and standards related to neighbourhood site design, land subdivision, urban renewal and construction techniques and materials.

This law recognises that it is the task of municipalities to carry out planning and urban development controls within their jurisdiction. Amongst the most relevant objectives of these municipal strategic plans and regulations are: property protection against proximity to dangerous or annoying uses, harmonious relationships between the various land-uses, convenient access of properties to public roads, adequate subdivision of land, adequate community facilities and public services, reservation of areas for future public uses, and rehabilitation of areas and prevention of their deterioration. To achieve these objectives, municipal strategic plans must contain the following:

- Development policy, including principles and norms on which the plan is based, as well as the objectives arising from the area’s needs and growth.
- Population profiles, including growth projections and distribution, as well as norms related to recommended densities. It is unclear, however, whether by “distribution” “age” or “gender” or both are meant.
- Land-use types (e.g. housing, commercial, industrial, educational, recreational, institutional).
- Analysis of location and size required for the following services: educational facilities, libraries, museums, public markets, parks, playgrounds, hospitals and clinics, etc.
- Analysis of needs and location of the following infrastructural services: water supply, sewerage drainage, rain drainage and solid waste disposal.

- Housing and housing renewal in terms of needs as well as with reference to areas that must be preserved, rehabilitated or refurbished.

For the elaboration of municipal strategic development plans, local governments have several options. They can develop the plans themselves, they can ask INVU to develop the plans or they can contract the plans to private companies through open bids coordinated by the Ministry of Economy. These three mechanisms allow municipalities with limited financial or human resources to find a suitable way of producing a strategic local government development plan.

For the adoption of a municipal strategic development plan, the local government is obliged to arrange a meeting in which citizens are informed of the details of the plan. Even though there is no process of public consultation in the form of an open vote, citizens can follow the process of plan preparation and can also appeal against the plan in court. Following this process, the plan goes to INVU for its approval and finally to the municipal council, where it must be approved by a majority of the votes. The plan becomes official once it has been published in the official journal (*La Gaceta*). One interesting aspect is that these plans are not submitted to the National Emergency Commission for the Prevention of Risks and Response to Emergencies for approval.

The **Zonation** regulations are key in urban disaster management in Costa Rica. These regulations comprise a map depicting the various zones, plus related metadata. Most importantly, a zonation regulation indicates where certain uses of land, buildings and other structures (e. g. agricultural, residential, industrial, commercial, public) are permitted. Other important measures that can be incorporated into a zonation plan (these are not compulsory) include the following:

- Target densities can be set for residential areas. This is important as recent experiences such as the Kobe earthquake highlight the increased fatalities in high-density areas, especially when there are no open spaces available for evacuation purposes.
- Maximum “plot coverages” can be set to guarantee some open space within a plot. A plot coverage of 60% in a plot of 400 m^2, for example, would translate into a maximum 240 m^2 of roof area, leaving 120 m^2 as open space. This is an important disaster mitigation tool as it can be used to force people to allow room for a garden where they can go in the case of an earthquake event.
- In the case of single-family dwellings, minimum plot sizes can be set in terms of plot area as well as minimum width and width/length relationships. For example, current regulations allow a minimum width of 6 m and a maximum width/length relationship of one to seven. This tool could be used to avoid extremely long parcels that could make evacuation to the roads difficult in the case of earthquakes.
- Maximum building height is also an important aspect in earthquake mitigation.

- One important aspect of a zonation regulation relates to what the law describes as “special zones”. These are zones where development should be contained or avoided. Amongst the cases mentioned are airports, historical heritage, natural resource conservation, and flood-prone and “dangerous” areas. Interestingly, there is no elaboration on what is meant by “dangerous” areas. Even though one could argue that natural hazards can be included under the heading “dangerous areas”, the Urban Planning Law is somewhat vague in terms of natural disaster mitigation. It would seem that this law has not been updated to reflect current views and priorities agreed internationally and supported by leading organisations such as the United Nations and the World Bank.

A certificate of zonation compliance is required from the municipality before preliminary building permits or commercial or industrial patents can be obtained. From this it can be inferred that prior to purchasing or renting a plot, one must first verify with the municipal planning office whether the intended use of that plot is permitted.

Another type of regulation is known as **Urban Renewal.** Its aim is conservation, rehabilitation or renovation of urban areas considered to have deteriorated or to be defective or decayed and that pose a threat to security, sanitation or the general well-being. All areas that a municipality considers to be in need of renewal will have land subdivision or building restrictions imposed upon them unless changes are made to improve the situation. The importance of these regulations is that they grant municipalities the right to expropriate land that can be redeveloped and sold to either the same or new owners. This is important because it highlights the disaster management measures of expropriation and redevelopment. Under the Urban Planning Law, both INVU and the municipalities can carry out expropriations.

INVU has issued standards related to construction, land subdivision and neighbourhood design. These are compulsory unless a municipality issues its own regulations. Since the Municipality of Cartago does not have tailor-made regulations, those contained in Law 7554 and related documents must be applied and enforced.

The **Land Subdivision and Urbanisation** regulations standardise access to roads, land subdivision and block design, and set land allocation requirements for common public spaces such as parks and community facilities. These regulations include minimum standards for the construction and design of roads; sidewalks; paved surfaces; water, rainwater and sewage pipelines; as well as electricity supply and street lighting. All subdivision of land in urban areas must first be approved by the municipality and later approved and registered at the National Cadastre. Some examples of measures included in these regulations that are of relevance to disaster management are:

- Donation of between 5 and 20% of the land for parks and community activities. This is important not only from the point of view of recreation but also from the point of view of evacuation during earthquakes – also temporary shelter can be built to house displaced families whose houses have suffered damage.
- A general prohibition on building within 10 m of either side of a river basin (5 m in the case of a creek).
- A ban on construction on terrain steeper than 25% to prevent future landslide problems.
- A slope stability study to be carried out on areas steeper than 30%.
- Drainage works in terrain steeper than 10% to avoid slope instability.
- Maximum road gradient of 20% to ensure access of emergency equipment and easy evacuation.
- Minimum road widths to ensure the access of fire engines and ambulances.

The **Construction** regulations are the most important regulations in terms of earthquake disaster prevention in Costa Rica and the most widely enforced due to a variety of factors, which will be described in more detail later in this chapter. Under this regulation, buildings are divided into three categories:

- Group A includes buildings where large losses of property or human life could occur, or those that are relevant during emergency situations, such as hospitals, public buildings, fire stations, police stations, jails, buildings for storing exceptionally valuable objects, buildings bigger than 400 m^2 where large numbers of people are concentrated, transportation terminals, pump stations, buildings for storing toxic, explosive or radioactive material, electric power plants and telephone exchanges.
- Group B includes houses, education facilities, buildings smaller than 400 m^2 where large numbers of people are concentrated, buildings for storing valuable items, industrial buildings not included in Group A, other buildings where people go to work but not included in Group A, fences higher than 2 m and structures whose failure could put other structures at risk.
- Group C includes isolated constructions and non-permanent buildings not used for housing or public use and not included in Groups A or B.

The calculation of design capacity depends not only on the traditional calculation of vertical and lateral loads[3] but also on coefficients assigned according to the classification described below (group A=1.20; group B=1.00; group C=0.70). It is clear that this construction regulation attempts to ensure higher structural design standards according to the occupancy and strategic importance of the building. This highlights the fact that structural design is not

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[3] *CU=0,75(1,4CP+1,7CT)+CV,* where CU relates to both gravitational and wind forces that buildings must be able to withstand (known as "design capacity"); CP relates to structural weight load, CT relates to temporal weight load, and CV to wind load.

being carried out in isolation; there is an explicit attempt to combat homelessness and ensure that response activities will not be hampered.

The Federated Board of Engineers and Architects (CFIA) have issued three major codes (seismic, hydraulic and electric). The present seismic code was issued in 1986 – although following the 1990 earthquake in Limón, it was considered that the boundaries of the macro-zonation (see Figure 6.3) should be revised. The code states that in the absence of a particular norm, other norms such as those of the American Society for Testing of Materials (ASTM) and the American Concrete Institute (ACI) should be applied. Strangely, even though flooding is a more serious problem in Costa Rica than earthquakes, the construction regulations hardly mention anything related to flood-proof construction.

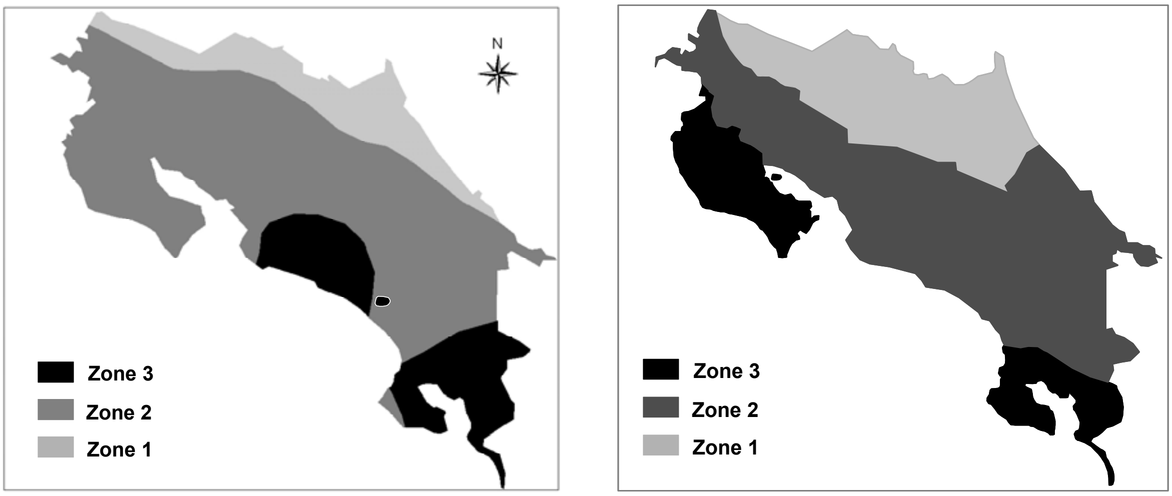

Figure 6.3: Seismic Zones (Colegio Federado de Ingenieros y de Arquitectos de Costa Rica 1986) and (Oviedo and Solís 2002). The map on the left illustrates the zoning of the 1986 Seismic Code; the map on the right illustrates the 2002 code. The new zonation resulted from recent research and the expansion of the earthquake catalogue due to the 1991 Limón earthquake. This map dictates minimum standards that should be applied to 1 and 2 storey buildings. As a result of the change in code, in some areas buildings constructed in compliance with old code are nowadays below the minimum standards.

One aspect that has vast implications for law enforcement relates to building permit fees. There are several institutions that issue preliminary plan approval, but it is the municipality that issues the final building permit. A fee of 1% of the cost of the project (according to a valuation made by CFIA) must be paid to the municipality by the owner or developer. There are only two exceptions: government projects are exempt and low-income housing projects that have been issued a “social interest status” by the Ministry of Housing and Human Settlements pay a fee of 0.25%. These fees are a very important source of revenue for municipalities and this helps to explain why municipalities are so efficient in tracking down those construction sites that lack building permits. This incentive, however, does not guarantee the efficiency of municipalities in carrying out the inspection of the building process from the point of view of controlling the quality of building materials and construction techniques. It is here that CFIA plays a major role in ensuring the quality of construction and building materials (see Section 6.6).

6.4 LAW OF THE NATIONAL COMMISSION FOR THE PREVENTION OF AND RESPONSE TO EMERGENCIES (CNE)

The National Emergency Law was passed in 1969 and it constitutes the basis under which the National Emergency Commission was founded. This decree resulted from the needs identified due to the 1963 and 1965 eruptions and lahars caused by the Irazú volcano in Cartago, as well as the 1968 eruptions of the Arenal volcano in Alajuela. Twenty people died due to a lahar that destroyed the neighbourhood of Taras in the north-western part of Cartago. The eruptions of Arenal claimed the lives of 120 people and caused considerable farming losses.

The Civil Defence Office was created in the 1960s; at first it was part of the President's office but it later became part of the Ministry of Public Works and Transportation (MOPT). A commission was formed by several members of the Cabinet with the task of administrating an emergency fund. This law not only allowed the commission to make "exceptional" use of public funds in the case of "calamity" but also to plan, direct, control and coordinate programmes related to protecting, safeguarding and reconstructing all those areas declared "emergency zones". In 1983, the law was modified, replacing the word "calamity" with the word "contingency", thereby giving the commission more scope for action.

The commission suffered a great drawback in terms of its public image in the early eighties due to a corruption case related to the misappropriation of a considerable portion of the emergency funds.

In 1986, a decree granted the commission the status of "institution" with its own offices and, although it was still legally part of the Ministry of Public Works and Transportation (MOPT), it functioned as an autonomous institution. The role that was given to CNE by this new decree included administrating projects funded by the emergency fund, responding to emergencies, as well as conducting education and awareness campaigns.

To cover operational costs, the commission is nowadays funded through the national budget. The commission has a great political responsibility and, at the same time, it is highly vulnerable to decisions made by central government due to the composition of its board of directors. This board must be composed of eight members representing the following sectors: health, public works, housing, social aid, environment, security and the Red Cross. Apart from the representative of the Red Cross, the other seven members are Cabinet appointees (typically ministers or presidents of autonomous institutions), and, as is the present case, there is usually not a single representative from the opposition parties.

During the 1990s, the two main CNE achievements were the separation of "response" from mitigation and the strengthening of local emergency committees, which are now regarded by CNE as the "warhorses" of emergency activities.

In 1999, a new law was passed and the commission officially became the "National Commission for the Prevention of Risks and Response to Emergencies", although its acronym remained CNE. CNE considers itself more of a coordinating than an executing entity. In its view, this allows the institution to carry out integral actions, avoiding the duplication of functions and waste of resources. Preparation and prevention programmes and projects are developed jointly with ministries, autonomous institutions, aid organisations, universities, foreign agencies and other organisations involved in the field of disasters. To achieve its objectives, the commission carries out the following actions:

- Prevention, reduction and preparedness by coordinating necessary technical and scientific research, as well as by issuing norms and conducting education or awareness-raising campaigns at both the institutional and the community level.
- Response by coordinating work of national and foreign institutions as well as by coordinating damage assessment, humanitarian assistance and recovery work by local emergency committees and other government and non-government institutions.
- Rehabilitation and reconstruction by coordinating and executing the regulatory plan. This plan should include the assessment of damage as well as the elaboration of policy on the allocation of resources and responsibilities to the various institutions involved in the reconstruction process.

CNE should in theory issue two important documents: a National Emergency Plan and a Regulatory Plan for Emergency Response, the first one being a general policy document while the second one should be area-specific. However, when such a document was requested at the planning department of the Municipality of Cartago, the officers claimed that they were not aware of its existence for their city and that the only document they possessed was a hazard atlas produced on 1:50,000 scale.

CNE is obliged to point out those areas of "imminent emergency risk" where no projects of a construction, enlargement or modification nature should be authorised in either full or partial form. This document should be sent to the municipality concerned, the Federated Board of Engineers and Architects of Costa Rica (CFIA), as well as to the National Housing and Urbanism Institute (INVU) and any other institutions involved in authorising construction and development works. All these institutions are obliged to observe and enforce these documents. It is evident that this information should be reflected in the zonation plan issued by the municipality to guide and control urban growth or redevelopment. CFIA is obliged to inform all its members of documents sent by CNE. The law makes explicit mention of the liability of those institutions and government staff members that overlook these documents, and this obviously constitutes an important pillar of urban disaster management. In the case of individuals who build in areas identified as of “imminent emergency risk”, the law allows CNE to coordinate both expropriation and demolition works.

A Regulatory Plan for Emergency Response can only be issued following the declaration of a “state of emergency”. A state of emergency can only be called by the President or the Minister of the Presidency. Following this declaration, CNE is responsible for developing a plan in consultation with the various institutions involved. The plan should contain the following items:

- Description and assessment of damage to humans and property, either already suffered or forecasted
- Mitigation measures
- Material and human resources (e.g. police, rescue brigades, demolition units) necessary to face the event
- Middle-term measures such as the rehabilitation of affected areas, and the suppression and prevention of the causes of imminent risk
- Distribution of tasks amongst the involved stakeholders

6.5 CENTRE FOR PREVENTION OF NATURAL DISASTERS IN CENTRAL AMERICA (CEPREDENAC)

CEPREDENAC was established in 1988 to coordinate and promote international co-operation and the exchange of information, experience and technological advice, with the objective of reducing natural disaster impact, and thus contributing to improved decision-making on planning and management in Central America. It therefore constitutes the umbrella organisation for natural disaster mitigation in Central America. CEPREDENAC is part of the Central American Integration System (SICA), an institution fostering the integration of Central America and overseeing agreements entered into by the governments of these nations.

SICA has declared the years 2000 to 2004 Central American Quinquennial for the Reduction of Vulnerabilities and Disaster Impact. Every country is expected to identify a target goal that should be achieved within the five-year period. It is suggested that emphasis should be placed on revising the legal framework to include prevention activities. The strategic plan of the Quinquennial is very comprehensive and worth mentioning as it provides a good example of an attempt to carry out sustainable disaster mitigation. The strategies are set according to 10 sectors: health, food and nutrition, education, housing and human settlements, farming, industry, transport, energy, environments and others. The strategic issues to be developed under each sector are listed in Table 6.1.

Sector	Strategies
Health	• Reduction of physical vulnerability of hospitals and water supply • Prevention, monitoring and control of epidemics and transmitted diseases • Preparation for response • Vaccination campaigns • Water safety and sanitation • Regional medication policy • Capacity-building on environmental health prevention
Food and Nutrition	• Detecting and monitoring food and nutrition requirements of vulnerable groups • Awareness campaigns on food hygiene • Production and consumption of nutritionally improved food by vulnerable groups • Quality control of food produced both locally and abroad
Education	• Setting up formal and informal education programmes on prevention and reduction • Training teachers in prevention and reduction • Vulnerability reduction of educational facilities
Housing and human settlements	• Updating and promotion of land-use norms based on vulnerability • Updating and implementation of rural and urban spatial plans • Updating of construction norms • Quality control of building materials
Farming	• Identification of crops resistant to drought and flood • Setting up an information system on the global or regional impact of climate phenomena on prices and international markets for relevant farming products • Promotion of irrigation and water storage projects in drought-prone areas • Setting up a plague forecast system based on climate change • Monitoring stocks of farming products to ensure nourishment and nutrition in the case of disaster or disaster alert • Design of a mechanism for the storage of basic products to be used in the case of disasters • Encouragement of sustainable farming practices • Establishment of a drought monitoring and warning system
Industrial	• Location, relocation or adaptation of plants and industrial production in suitable sites • Protecting the environment and the human settlements from industrial waste
Transport	• Vulnerability reduction of infrastructure (i.e. ground, air and maritime transport)
Energy	• Vulnerability reduction of energy generation, transmission and distribution at a local level but also for regional interconnecting lines • Reduction of the effects of droughts on hydro-electric generation
Environment	• Protection and recovery of slopes, agricultural frontiers, river basins, wetlands, coastal zones, forests protecting water resources, pollution control as well as transport and disposal of toxic waste

Table 6.1: CEPREDENAC Strategy

One of the challenges for CEPREDENAC relates to carrying out its duties in the light of the popular rejection of the idea of economic and political regional integration. As is the case elsewhere where integration has been or is being attempted, the Central American governments support integration mainly for trade reasons, while the general population rejects it mainly on historical grounds. In Costa Rica, for example, popular support for a Central American Union is extremely low.

6.6 CIVIL CODE

Since 1888, the Civil Code has established the responsibilities related to the design and construction of buildings and bridges. This document is a fundamental pillar in risk prevention in Costa Rica and one that has helped enormously in avoiding high earthquake risk levels. The Civil Code states that both the designer and the building contractor face liability for property damage for a period of five years commencing on the date that the building is handed over to its owner by the building contractor. The only exception contemplated is in cases where the construction process has been delayed due to financial problems attributed to the owner. The designer is liable for errors in the construction plans while the building contractor is liable for faulty execution of the work and for using building materials different to those stated in the construction plans and building specifications.

The Civil Code has been supplemented by the Organic Law of the Federated Board of Engineers and Architects of Costa Rica (CFIA). This law not only gives more details about the responsibilities of both the individuals or companies involved in the design and construction but also sets the responsibilities of the client or future owner.

6.7 LAW OF THE FEDERATED BOARD OF ENGINEERS AND ARCHITECTS OF COSTA RICA (CFIA)

This institution was founded in 1941 under the name “Board of Engineers” but it was not until 1971, when Parliament issued the Organic Law of the CFIA that it was granted a major role in earthquake vulnerability prevention. According to this law, this institution is in charge of regulating all building design and construction projects undertaken in Costa Rica. The most important roles of this institution are:

- Capacity-building of its members and the general public, in the form of courses on new regulations, building practice and new technology
- Granting preliminary construction approvals (the final building permit is issued by the municipality)
- Issuing building codes (e.g. seismic building, electricity and hydraulic sanitation codes),
- Enforcing codes
- Providing guidance and advice to both public and government institutions if requested
- Protecting the interests of its members

- Punishing members for unlawful or unethical acts
- Resolution of conflicts between members and clients

Individuals as well as companies carrying out consulting and construction in the field of buildings or neighbourhood design must be registered with the Board. Registration is therefore compulsory; individuals conducting work without registration face prosecution. On the other hand, members who have violated building regulations or have violated the “Ethics Code” face up to two years of suspended membership, which translates into inability to carry out work and therefore to earn a living.

Phases	**Sub-phases**
Plans and documents	• Preliminary studies • Preliminary project • Construction plans and related construction specifications • Budgeting
Control and execution	• Inspection • Technical direction (includes inspection, programming and control) • Supervision • Administration
Others	• Basic studies • Investment fiscalisation • Supervision

Table 6.2: Phases in the Construction Process

The reason why this law complements the Civil Code of 1888 lies in the establishment of professional responsibility according to a variety of phases. An engineer or architect can be responsible for either an entire project or for single phases. Basically the phases that are identified can be broadly grouped into plans/documents and control/execution of works. Table 6.2 gives an insight into the variety of tasks that can be carried out.

According to this law, all construction, reconstruction and land subdivision works must be designed and directed by a member of the Board. A contract between the client and the professional is compulsory and must be registered at CFIA in order to apply for a municipal construction permit or to request land subdivision. This contract, known as a “consulting contract” (*contrato de consultoría*) is very important in urban disaster mitigation as it records the responsibilities of architects, engineers and land surveyors and therefore sets the scene for liability.

Some of the phases described before are of a compulsory nature while others are optional. Obligatory phases that must be contracted out to a member of the Board are preliminary studies and project design, construction plans (including specifications) and technical direction. Some phases are optional (e.g. detailed budgeting) while others (e.g. administration) could be carried out by the client/owner himself. The person or company carrying out the preliminary studies is responsible for the soil mechanics study (the Foundations' Code specifies the minimum requirements for a soil profile). This stage is very important as an incorrect soil profile could lead to an unsuitable structural design and therefore, to property damage. A preliminary project poses little possibility of liability, as this phase comprises the plan and façade design as well as a very rough estimate of costs. The person or company responsible for the construction plans and related construction specifications is highly liable as this phase comprises the structural, electric and hydraulic designs which if faulty could lead to property damage. For the actual construction process, the person acting as technical director has the greatest responsibility as he oversees the construction process and reports back to the owner and to the Board through a black book that is then kept for a period of five years.

The Board is financially sound due to yearly membership fees paid by its members and the fees that must be paid to obtain CFIA preliminary building permits. In most cases, this fee represents 0.10% of the value of a given construction permit, the valuation being set by CFIA itself. The only projects exempt from these fees are government projects that have been given “social interest” status by the Ministry of Housing and Human Settlements. These projects are typically low-income housing projects funded by government-owned banks.

6.8 LAW FOR THE ESTABLISHMENT OF AN ANTI-SEISMIC CODE FOR CIVIL WORKS

This law states that all constructions and civil works carried out in Costa Rica must comply with minimum design and anti-seismic construction norms. The Cabinet issues minimum norms by means of regulations based on the advice and opinion of the Federated Board of Engineers and Architects (CFIA) in its role of “obliged collaborator”. The objective is to protect life as well as to ensure the functioning of essential facilities and to minimise property damage following a seismic event.

The objectives of these norms are to ensure that buildings and civil works designed and constructed will:

- Withstand minor earthquakes without damage
- Withstand moderate earthquakes with only some non-structural damage
- Withstand earthquakes of major intensity without collapsing and with only some structural damage that can be preferably repaired

This law is important not only because it states seismic design targets but also because it limits to some extent the liability that professionals could face for various types of earthquake magnitudes. There is no mention, however, of what is meant by the three types of earthquake (minor, moderate, major) and one could therefore claim that this lack of definition could lead to conflicts. One important feature of the code is a ban on construction within 50 m of active faults. This is important from the point of view of ground rupture (refer to Chapter 3).

Another significant aspect of the code is the minimum temporary design load established based on the use or function of the building (refer to Table 6.3). This highlights an issue commonly overlooked by municipal planning offices, related to the granting of permits for change of building use. Such changes can lead to higher vulnerability since structural elements and floors can be subjected to higher loads than originally intended.

Use of Floor	**Load** (kg/m^2)
Residential	250
Office	300
Commercial, warehouses or factories – light weight goods	500
Commercial, warehouses or factories – medium weight goods	650
Commercial, warehouses or factories – heavy weight goods	800
Gathering places without fixed seats	500
Gathering places with fixed seats	400
Car parking	400

Table 6.3: Minimum Temporary Design Loads (extract from: Colegio Federado de Ingenieros y de Arquitectos de Costa Rica 1986)

6.9 NATIONAL STATISTICS SYSTEM LAW

This law was issued in 1998 and its importance lies in the “public interest” character given to the production and diffusion of timely and reliable statistics, considered as a basis for efficient private and public management. The National Statistics System (SEN) is created with the National Statistics and Census Institute (INEC) as coordinating entity and is composed of public sector institutions. The role of SEN relates to rationalising statistical activities. One of the weaknesses of this document, however, is the lack of mention of the institutions that should be part of SEN. Interestingly, there does not seem to be any representation of the private sector clients or users of this information at SEN.

The most relevant aspect of this law for the purpose of this research is the concept of confidentiality, and there seems to be a serious misinterpretation of the law by INEC’s Information Centre. The law states that data supplied by individuals or companies can only be published as “global figures”, unless there is written consent from the individual or the company who has provided the data to the census surveyor. The contradiction between the legal framework and actual practice lies in the definition of “global figures”. The law states that “global figures” relate to those that contain figures on three or more individuals or companies. Since INEC prevents the general public from having access to data at the census tract level for “confidentiality reasons”, one can conclude that a problem of interpretation or implementation of the law exists. This database is highly relevant to the planning process, not only because of the nature of the information contained but also because of its level of detail.

Another important aspect relates to the obligation of institutions belonging to SEN to hand in any requested data. Not only are they obliged to do this, they must also supply truthful and timely data; the law indicates that failure to do so might lead to sanctions. Regarding the periodicity of the census surveys, the law establishes that there will be at least one housing and population census every 10 years and an economic and farming census every five years. Of interest to the research are the household census and the construction permit statistics, although the law does not state their periodicity.

Having said that, because of inadequate emergency planning, one cannot take it for granted that a census will be carried out in the programmed year. The 1994 National Population and Housing Census was postponed until the year 2000 as the decision was made to divert funds to reconstruction activities to repair property and infrastructure damage caused by Hurricane Caesar.

6.10 CONSTITUTIONAL JURISDICTION LAW AND PARLIAMENTARY OMBUDSMAN LAW

In the attempt to achieve transparency and accountability in urban development (two important principles of good governance), two relatively recently established institutions play a major role: the Parliamentary Ombudsman (*Defensoría de los Habitantes*) and the Constitutional Court (*Sala Cuarta*).

The Parliamentary Ombudsman was established in 1992 (the Swedish Ombudsman established in 1809 was the inspiration for this). The role of this institution is to protect the rights or interests of individuals or companies against the arbitrary acts of the public sector. The Ombudsman reacts to complaints of violations deriving from the action or lack of action by public sector officials. This institution has been very active in the fight against corruption and is one that has considerable popular support.

The Constitutional Court was established in 1989 and its role relates to guaranteeing the supremacy of norms and constitutional principles, as well as their uniform interpretation and application. This institution also resolves conflicts related to the competence (who does what) between the various levels of government or institutions. The “confidentiality law” applied by the National Statistics and Census Institute (INEC) is a good example of a case that should be presented at the Constitutional Court. It could be argued that the Census Bureau misinterprets the law and by denying access to census tract information, it is hampering urban disaster management and urban planning in general.

6. 11 CONCLUSIONS

One could argue that liability and incentives constitute important push-pull factors in urban disaster management (see Figure 6.4). From the analysis of the legal framework, it can be concluded that the framework is comprehensive and that the linkages between the various institutions are efficient in ensuring enforcement and compliance. The creation of the Parliamentary Ombudsman and the Constitution Court has ensured that misinterpretation, neglect or omission by government institutions can be tackled. Moreover, there are two other important factors that ensure enforcement and compliance: accountability is ensured over a five-year period of **liability** for property damage (which forces institutions and individuals to act lawfully), while **construction taxes** constitute an important financial incentive for institutions to oversee the development and construction processes.

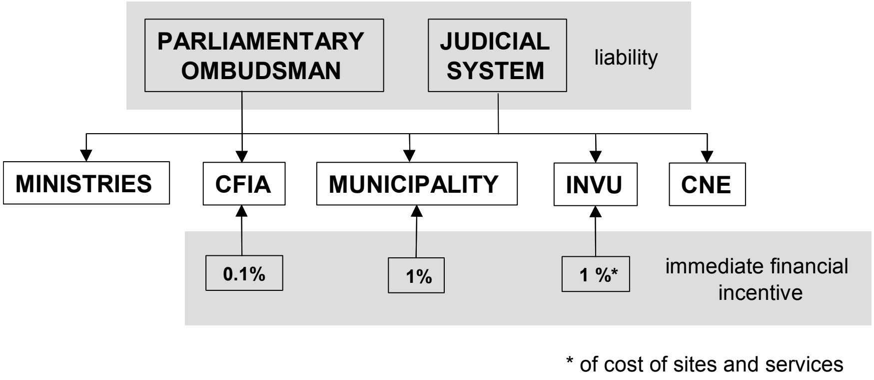

Figure 6.4: Liability and Incentives in Urban Development

With the decentralisation of duties from central to local government under way, municipalities will be more financially sound in the future. This process is important as for decades local governments have argued that they are unable to carry out inspection and planning properly due mainly to financial constraints. The National Urbanism and Housing Institute (INVU), a leading organisation in guiding urban development, has been severely financially constrained for decades and this constitutes a serious weakness that must be addressed.

Chapter Seven: THE CASE OF CARTAGO

This chapter introduces the case of the city of Cartago in Costa Rica. First, a review will be made related to the history of the city in terms of its urban development, the evolution of construction techniques and materials, the perception of seismic events and the impact of natural disasters. Finally, a review of available datasets will be made from the point of view of opportunities and constraints. In Chapter Eight the methodological aspects related to data inputs for risk assessment will be discussed and the earthquake risk assessment results will be presented.

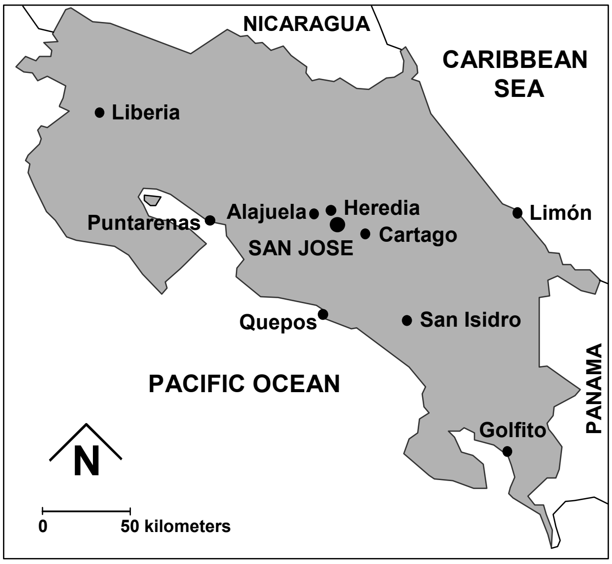

Figure 7.1: Location of Major Cities in Costa Rica

7.1 JUSTIFICATION OF CASE SELECTION

The city of Cartago in Costa Rica constitutes an interesting case study due to its high susceptibility to hazards and to the way natural disasters have shaped its history and urban development process. It lies 1,439 m above sea level in what is known as Costa Rica's Central Valley. Cartago is located in a very fertile part of the valley known as the Guarco Valley (see Figures 7.1 and 7.7). The fertility is a consequence of the periodic eruptions of the Irazú volcano. The city is the agricultural centre in the Guarco Valley; its inhabitants are known as *paperos* (potato people) since most of the potatoes harvested in Costa Rica are grown on the foot slopes of Irazú. According to the 2000 National Population Census by the National Statistics and Census Institute (INEC), the province of Cartago has a population of 432,923. While 125,000 live in the city of Cartago, some people commute each day to San José (22 km away) for work.

The Municipality of Cartago is a typical Costa Rican municipality in terms of financial and human resources. In order to guarantee the transferability of risk assessment within the Costa Rican context – one of the objectives of the research – a decision was made not to study a city that had data available as a result of some exceptional research project or wealthy nearby research institute.

7.2 HISTORICAL BACKGROUND

Little is known about pre-Columbian cities in Costa Rica. According to Troyo (1998), there are around 3,000 small archaeological sites of ceremonial, residential, burial, raw material extraction or instrument elaboration nature in the Costa Rican territory. These sites confirm that human occupation of present Costa Rican territory dates back to 10,000 B.C.

Many authors seem to agree that the population in today's Costa Rica was very small at the time of the arrival of the Spaniards, and most consider mineral wealth and location to be the explanations for this. In ancient times, trade was carried out using gold as currency, while jade was used as a symbol of status. Many jade figures have been found during archaeological excavations; however, Costa Rica lacks jade and has very limited gold deposits. This helps to explain the very low indigenous population and the limited level of development compared with the grand Mesoamerican (e.g. Aztec, Mayan) and South American civilisations (e.g. Inca, Tihuanaco). According to Thiel (in Fonseca and Barrascout 1998), there were only 27,200 inhabitants between 1522 and 1569, while Baker (2001) quotes a figure of around 20,000. So far, the only author that has questioned these figures is Ibarra (in Solís 1996), who quoted a figure of around 400,000 inhabitants.

In terms of location, Troyo (1998) believes that the boundary of the Mesoamerican civilisation was where Honduras lies today, while the boundary of the South American civilisation lies between Bogotá and Armenia (Colombia), with the Andes as the boundary to the east. Costa Rica was, in what she describes as the "Intermediate Area", a type of "no-man's land".

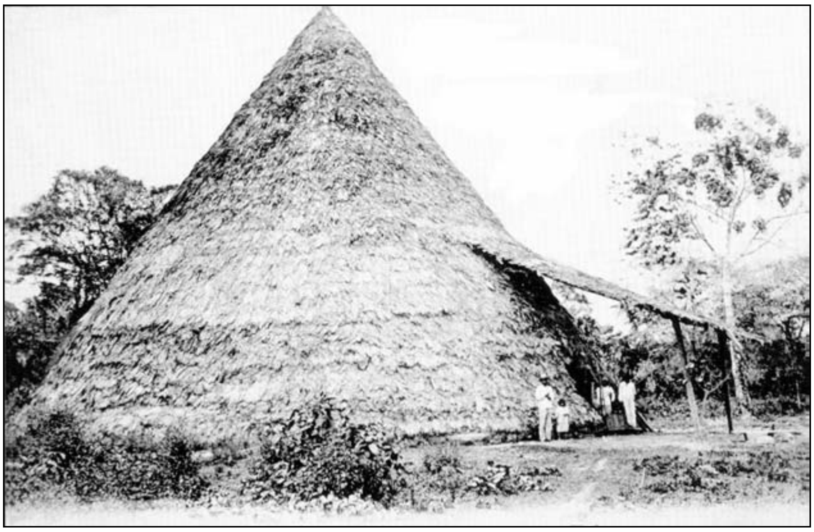

Figure 7.2: Typical Costa Rican Native Palenque (Fonseca and Garnier 1998)

The population was hierarchically organised into *cacicazgos*. The cacicazgo was a socio-political structure whose leaders, known as *caciques*, based their power upon a mythical ancestral origin combining political and religious power. Ibarra Rojas (1990) considers that during the XVI century, there were at least 13 caciques in the country and communication and trading amongst them was carried out on a regular basis. Agriculture was the most important economic activity. Their diet was based mainly on maize, roots and beans and supplemented with wild fruits, fish and animals.

People thought of themselves as being part of nature; therefore there was equilibrium in their relationship. The types of materials used for the construction of their buildings, as well as the layout of their villages, was of a very “organic” nature. The layout of the villages was very irregular. Buildings were commonly constructed on top of either a rectangular or a circular rock platform. The size of these platforms ranged between 6 and 35 m in diameter. The height of the platform ranged from a few centimetres to around 2 m. The average yearly precipitation in Costa Rica is 3,300 mm; therefore the elevation of buildings by means of rock platforms highlights the extent to which the weather was taken into account. The walls were frequently composed of wood or bamboo sticks and sometimes they were plastered with clay. In some cases, floors were of fine baked clay. In buildings known as *palenques* (see Figure 7.2), the palm tree or straw roof extended all the way to the floor. Because of the non-lasting character of these building materials, only a few of the platforms remain. Even though people were highly skilled in baking clay objects for various purposes, there is no evidence that suggests the use of clay tiles as roofing material. The avoidance of heavy roofing materials seems to suggest that earthquakes were taken into account and there was therefore an explicit attempt to live in harmony with the environment.

In 1492, the Spanish discovered what to them was an unknown continent on their way to India. Following this fortunate discovery, the Queen of Castile and the King of Aragón launched the Spanish *Conquista*. This discovery was not only an act of good luck but also one that bailed Spain out of a precarious financial situation. Expelling the Moors and the Jews had been both a religious success and a financial disaster. Spain’s finances suffered greatly following this forced expulsion as both the Moorish and Jewish communities were highly wealthy. This unexpected “New World” provided not only an opportunity to recover from economic recession but also an opportunity to create a vast empire controlling major trading routes that would provide them with economic and military supremacy over the rest of Europe.

Christopher Columbus landed on the east coast of Costa Rica (present-day Limón) in 1502 on his fourth voyage to the “Americas”. Having seen a few inhabitants wearing golden collars, he named the land *Costa Rica*, meaning “rich coast”. Expeditions followed, only to discover that this name did not quite reflect the mineral wealth of this land. After several expeditions, the word spread that this land lacked gold, silver and precious stones. Furthermore, the area also lacked inhabitants to act as servants or slaves and therefore the

Spanish became more interested in territories to both the north and to the south, such as Nicaragua and Panama, where people and gold were in better supply. As Baker (2001) points out, for the next four decades Costa Rica was virtually left alone. The conquest of Peru by Pizarro in 1532, as well as the first of the great silver strikes in Mexico in the 1540s, turned eyes away from southern Central America. Guatemala became the administrative centre for the Spanish Main in 1543, when the Captaincy-General of Guatemala, answerable to the Viceroy of New Spain (Mexico), was created, with jurisdiction from the Isthmus of Tehuantepec to the empty lands of Costa Rica. Since this province was the most distant from the headquarters in Guatemala City, contact was weak and the province enjoyed relative freedom. Baker (2001) even points out that in fact money became so scarce that the settlers eventually reverted to the native method of using cacao beans as currency. This helps to explain the different process of colonisation that took place in Costa Rica, when compared with other nearby countries such as Guatemala and Mexico. The economy evolved slowly under conditions that favoured neither the development of large colonial-style haciendas nor the feudal system of other Spanish enclaves, the nearest example being Nicaragua. The Spanish founded some villages along the Caribbean coast, but most of these enterprises failed because of the lack of native people to do the work and because of British pirates who were constantly looting these Spanish coastal villages with the aid of indigenous people.

The natives were exploited under a system of forced labour that used them as guides for exploration, as carriers of goods and/or as food suppliers. Eventually, the Spanish moved inland and founded the city of Cartago, amongst others. In 1564 Vásquez de Coronado, founder of Cartago, brought a group of settlers willing to establish themselves on the land and enough cattle to ensure their success. In 1542 “New Laws” were issued by Spain, prohibiting slavery and institutionalising the *encomienda* system (also known as *repartimiento*). Indigenous people were distributed amongst the Spaniards and were forced to either work for their “masters” or pay in cash or kind instead. However, it was not until 1568 that, due to the constant rebellions by indigenous people, Governor Perafán de Rivera decided to implement the encomienda system in Cartago. From 1569 to 1611 the natives paid their master, or *encomendero*, a tribute in the form of agricultural products and handicrafts (ceramic and textile goods). To fulfil the quota, they were exploited to the extreme, thus provoking a dramatic decrease in population. Fonseca and Quirós (1993) consider that this is the reason and not, as has been traditionally believed, that diseases caused a high mortality rate amongst the natives during the first century of Spanish rule.

The layout of Cartago was carried out simultaneously with the issuing of the Law of the Indies[4]; therefore it is unlikely that there was knowledge in Cartago about the details of such

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[4] In 1523, Charles V issued a series of preliminary norms related to the criteria for site selection for founding new cities. In 1573, Philip II issued the “Laws of the Indies” related to the selection of sites specifically for founding cities in the New World, but also giving specific standards for street layout and street width, as well as the location of the main square, churches and residential, commercial and institutional buildings.

a law. The layout, however, does comply with this law, which indicates that there were already some agreed principles on how to found cities and how to design their structure.

Although Cartago was founded in 1564, present-day Cartago dates from 1575 – the original site was abandoned as it had been founded on extremely muddy terrain. The settlement was therefore relocated about 2 km northeast of the original site. Figure 7.3 illustrates the layout of the city of Cartago as designed by Alonso de Anguciana in 1572. The layout was based on a grid of square blocks of 100 x 100 *varas* (1 vara = 0.83 m). Squares were typically divided into four plots (refer to Figure 7.3); "distinguished" families received two adjacent plots close to the main square while ordinary citizens received only one plot. When all the lots were occupied, other squares would be laid out. Eventually these plots started to be subdivided, mainly for inheritance purposes.

Villages were first linked using existing indigenous paths. These paths, however, had to be widened by the Spaniards to allow the transit of horses and carriages (the indigenous people did not use horses). The "Royal Trail" linked Cartago with the province of Nicaragua, the "Mules Trail" linked Cartago with Panama, while the "Matina Trail" linked Cartago with the village of Matina, located near present-day Limón (refer to Figure 7.1).

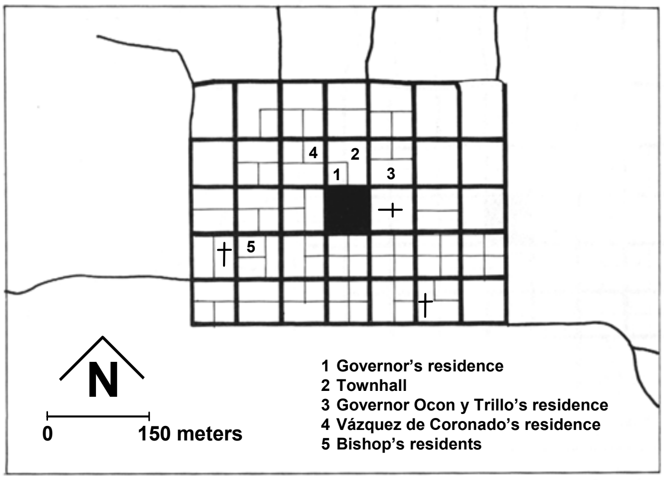


Figure 7.3: Cartago's Road Layout Design by de Anguciana in 1572
(adapted from Ponce 1993)

In 1590 Velázquez Ramiro founded a hamlet nearby under the name of San Juan de los Naboríos. This hamlet, as well as the *Puebla de los Pardos* (hamlet of the "dark skinned") confirms the existence of an apartheid system. The Spanish, the "creoles" (half-Spanish half-indigenous people) and the indigenous lived in different parts of the city. As the terrain is flat and there are no major geographical features, the irregular street layout of the Puebla de los Pardos seems to suggest that this part of town was neglected by the Spanish.

Cartago grew at a slow pace. According to Ponce (1993), by 1608 only 57 houses had been erected; in 1650 there were 70 houses and by 1690 87 houses (see maps adapted from Peraldo and Montero 1994 in Figure 7.4). A full century after its founding, Cartago had less than 100 houses and only one church, which, according to Baker (2001), were all destroyed by the eruption of the Irazú volcano in 1723. No great infrastructural works were carried out during the colonial era due to limited capacity and the size of the population. According to Fonseca and Garnier (1998), at the end of the XVIII century there were only 60,000 inhabitants in the province of Costa Rica. Another important factor was the fleeing of native people from Cartago into remote mountains to avoid exploitation. This caused a major problem of labour supply for the Spaniards. Moreover, the Spanish government did not build any grand buildings or fortifications because of the limited strategic importance that this province had for the Crown. Water supply was provided by means of mills located along the rivers and open channels that conducted the water into the city. It was not until 1800 that these open channels were covered with flat protective stones. The streets were not paved until 1782.

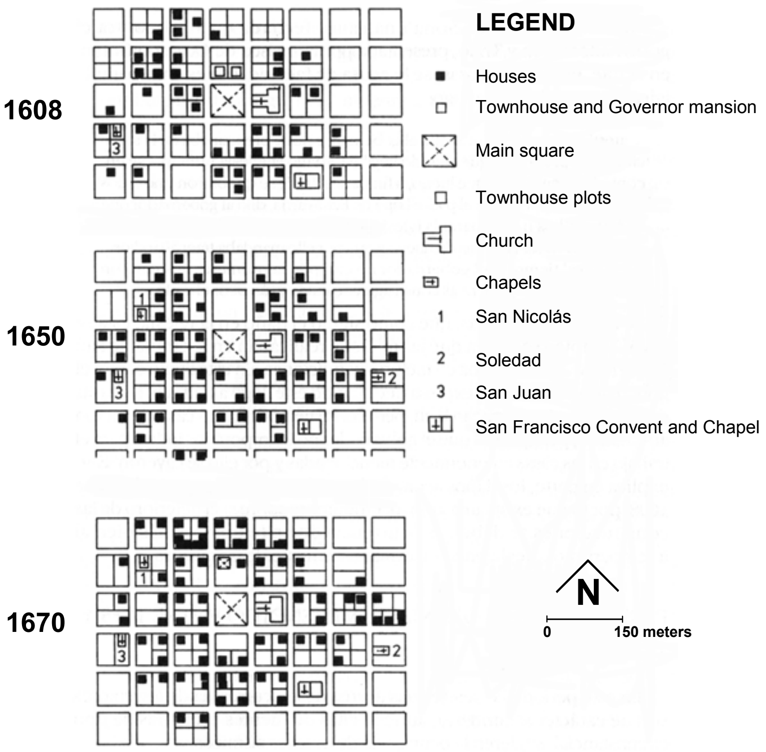


Figure 7.4: Occupation of Building Blocks during First Century
(adapted from Peraldo and Montero 1994)

During the first years after their arrival in the New World, the Spanish were forced to solve their shelter problems by using the most widely available materials: mud, wood and straw. During the XVI century, houses built of mud walls with palm tree or straw roofs were predominant in Cartago. Later on, as the village progressed economically and more skilled people arrived and settled down, traditional Spanish materials and construction techniques were applied (mud bricks plastered with lime stucco, carved wood and clay tile roofs).

Figure 7.5: Typical Adobe Walls

According to Troyo (1998), the use of clay tile roofs in Cartago can be traced back to 1607. In terms of construction materials, mud was probably the only common denominator between the Spaniards and the natives. While the natives used it to cover up gaps between the various pieces of wood or bamboo that composed the walls, the Spanish used it to construct heavy bricks from mud, straw and manure, known as *adobe*.

Adobe was used in Spain as it was conducive to a very pleasant indoor temperature. However, while this might have been an issue in Spain during summer, it was definitely not so in Cartago, where temperatures range between 12 and 24 degrees Celsius throughout the year. On the other hand, heavy adobe walls were very vulnerable to earthquakes, especially if topped by heavy wooden rafters and a clay tile roof. It can be concluded that there was little adaptation in terms of construction techniques or building materials by the Spanish settlers. This is surprising as it was not the case with other European settlers that moved into the New World. The reason might lie in the compliance with a set of laws issued in Spain by a king who never visited the New World and consequently issued laws containing some standards that were inappropriate from the point of view of earthquake hazards. This is by no means surprising as earthquakes do not occur in Spain and earthquake-proof construction was therefore unheard of.

With the exception of one single house, stone was only used in Cartago for the construction of churches. It was not until the end of the XVII century that stone construction was introduced, but it was seldom used until the middle of the XVIII century, when the commercial boom due to tobacco exports improved the financial situation and allowed the use of more expensive materials. This method differed from adobe in that ditches were excavated and a foundation was first built. Stone walls were always plastered with lime stucco.

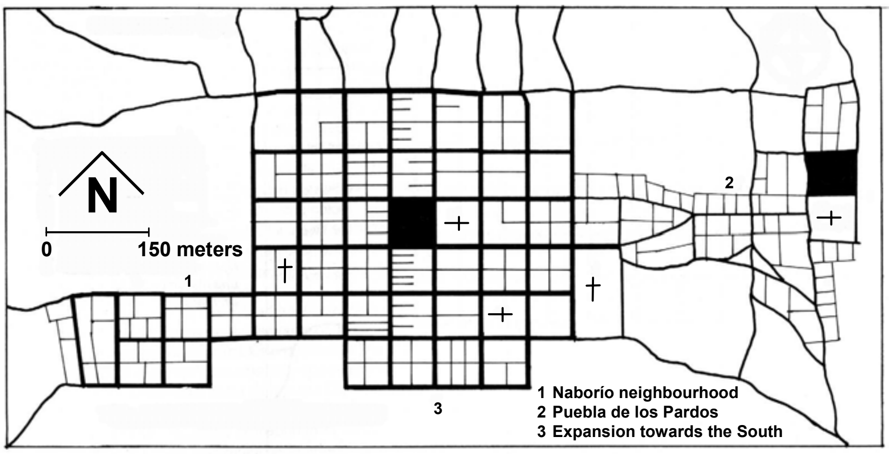


Figure 7.6: Cartago’s Road Layout in 1690 (adapted from Ponce 1993)

Wood was of very high quality and in good supply. It was not used for building walls during colonial and early republican days, however, because of the shortage of nails and tools such as saws, hammers and axes. The use of wood was restricted; it was used mainly for doors, columns and rafters. For example, only very wealthy families could afford wooden floors.

As pointed out by Solís (1996), the anti-colonial feeling was not as deeply rooted in Costa Rica as in other parts of Latin America. The system did not create deep conflicts or contradictions and, to some extent, economic deprivation prevented the natives from being massacred, as there was hardly anything worth looting. Ethnic tension was never as high as in other parts of the Spanish Empire, mainly due to the lack of population at the time of the arrival of the Europeans. The only complaints arose from the commercial sector, whose members felt limited by the trade restrictions imposed on them by the Spanish Crown. There was therefore no reason for a violent struggle. The Declaration of Independence was signed in the city of Guatemala on the 15th of September of 1821 and ratified in Cartago on the 29th of October at the expense of not one single drop of Costa Rican blood.

Soon after independence, a series of important changes took place. At the time of independence, most of the population lived in or around the capital city of Cartago. During the XVIII century, though, the Creole peasants started conquering the forest in a wave of colonisation towards the western side of the Central Valley. The cities of Heredia (1706), San José (1737) and Alajuela (1782) were founded. Next, in a circular pattern, the properties around them were cleared and planted. San José had become the economic centre due mainly to the tobacco boom during the second half of the XVIII century and coffee exports during the XIX century.

During the first half of the XVIII century, the capital was moved to San José. There are three reasons that explain this decision:

- Cartago had suffered great physical and economic losses through earthquakes and lahars
- Cartago had been left behind by San José in terms of economic and demographic growth
- Cartago had lost in the civil war with San José and Heredia

In terms of the civil war, the conservative and aristocratic leaders of Cartago and Heredia had found themselves at odds with the more progressive republican leaders of San José and Alajuela. While Cartago and Heredia wanted to join Mexico, San José and Alajuela wanted to join the Central American Federation. The local quarrels quickly developed into a civil war in which Cartago and Heredia were defeated. Interestingly, more lives were lost during the war that broke out between the leading cities than in the independence process.

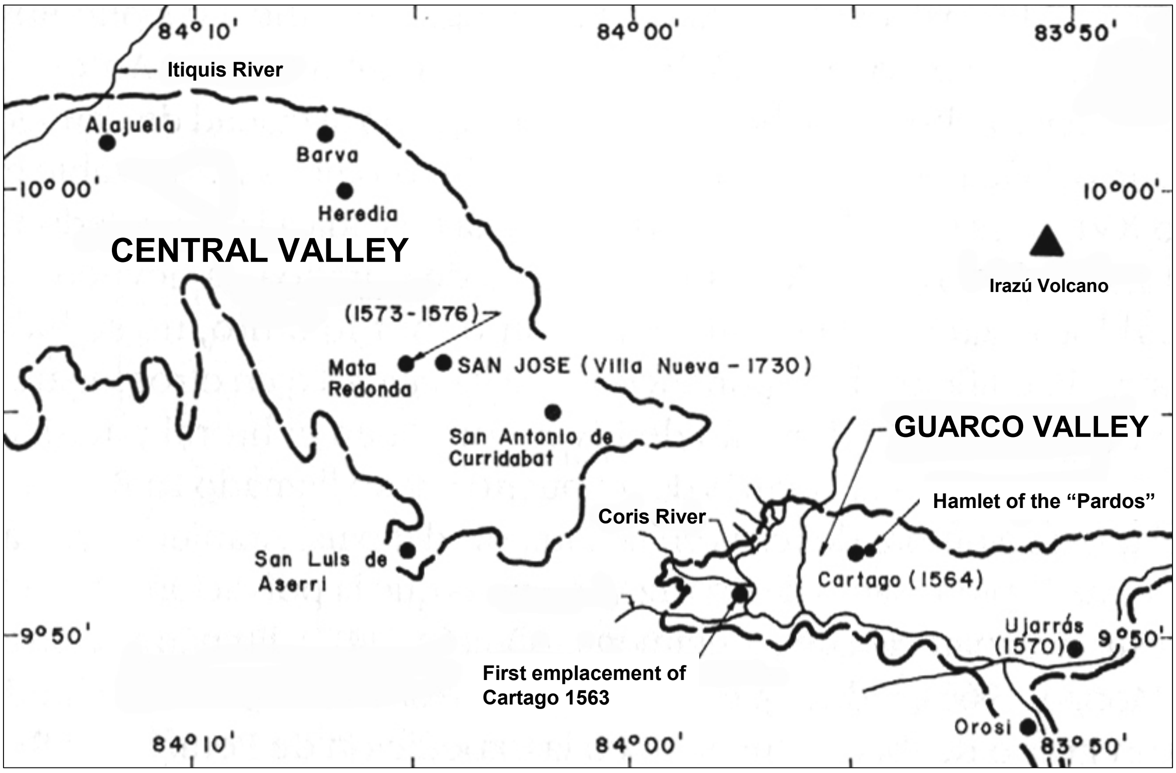


Figure 7.7: Location of the Various Cities in the Central Valley

Fernández and Céspedes (1910) point out that after the seat of government was removed from Cartago in 1823, the city seemed to be dying, its population falling to about 3,000 inhabitants by 1890.

Although the populations of San José, Alajuela and Heredia rose, the country remained mostly rural. According to Samper (in Solís 1996), even in 1927, 81% of the population of

Costa Rica was rural. For this reason, many authors, such as Baker (2001), have described Costa Rica as a “rural democracy” characterised by individuals who were extremely individualistic and somewhat egalitarian.

The earthquake of 1841 destroyed Cartago and killed 31 people. Out of a total of 600 houses, 291 collapsed, while the rest were heavily damaged. Only four houses built of rock masonry withstood the earthquake properly. From a total of seven churches, five collapsed and two were heavily damaged. The main church, which had already been heavily damaged by a tremor in 1781, was destroyed in 1841. The Church of Los Angeles located in the Puebla de los Pardos, which had already been damaged by the 1715 earthquake, was one of the two that were heavily damaged in 1841. It was then destroyed by the 1910 earthquake. Another earthquake, this time in 1811, damaged the town hall.

Following the earthquake of 1841, President Braulio Carrillo issued a series of decrees with very concrete objectives:

- Reconstruction of Cartago
- Regulation of existing construction practices and design
- Planning the funding sources for the construction of public buildings such as churches, town halls, jails and military headquarters

These decrees defined which buildings had to be constructed and where they would be built. It also specified a minimum street width of 16 varas (1 vara = 0.83 m). This measure did not prove particularly popular as some inhabitants lost part of their plots, and compensation procedures had to be put in place. Another important issue was limiting the height of houses to one floor only. To ensure proper ventilation and a uniform urban landscape, the heights were standardised at four and a half varas (3.7 m). Only two churches would remain (La Parroquia and La Soledad), while the remains of the other churches would be used to reconstruct these two as well as neighbourhood chapels.

The decision relating to the reconstruction of only two churches was overlooked. It was not easy to extinguish two important colonial religious institutions: the Franciscan cloister, headquarters of the only missionary order in the province of Costa Rica, and the Church of Our Lady of Los Angeles, former colonial brotherhood, place of pilgrimage and sanctuary to native Cartago since 1782. These churches, along with La Soledad, El Carmen and San Nicolás were rebuilt between 1845 and 1865. Strangely, the last church to be rebuilt was the parish church. Its reconstruction did not start until 1861 and was then abandoned in 1910, when people gave up after an earthquake ruined what had been erected so far, thinking that this constituted a divine message (see Figure 7.8).

Figure 7.8: Ruins of the Parish Church at Cartago
(its reconstruction abandoned after the 1910 earthquake)

The other important issue contained in these decrees was the section entitled “Instructions for Rebuilding with Strength”. This section of the decree constitutes the first written account of building regulations in Costa Rica. This was developed based on an analysis of construction systems used since 1823. Three main construction systems were regulated:

- Wood-frame walls
- Wooden poles anchored to the ground
- Stone and mud-brick walls

One important step forward was the ban on the adobe construction system and its replacement with the *bahareque* system (see Figure 7.9). The bahareque consists of a wooden and bamboo frame infilled with mud and clay tile fragments. This system was considerably more resistant to earthquakes.

The 1841 norms of Carrillo highlight not only the role of the government in guiding city growth and redevelopment but also the status of relations between State and Church during the XIX century, with an increasingly stronger government.

The next important event was the deadly and destructive 1910 earthquake. The casualty rate was extremely high. Fernández and Céspedes (1910) point out that one in eight inhabitants perished (1,500 out of the 12,000 inhabitants). This constituted the third time that Cartago lay in ruins. The same authors make a very relevant remark related to the property losses. They mention that adobe, of which most houses in the city were constructed, crumbled easily, while the few houses that remained standing were those built with wooden frames.

Figure 7.9: Typical Bahareque Wall

A very significant step forward was made following this event. The population reconstructed their buildings with wood or corrugated metal sheets, materials that had not been used as wall material before (refer to Figure 7.10). Only in Cartago can it be observed that houses had a mixture of adobe and corrugated metal walls, the corrugated metal replacing the part of the building that collapsed during the 1910 earthquake. The other interesting aspect is that clay tile roofs were replaced with corrugated metal sheets in an effort to lower the vertical load on the walls. The traditional Spanish architecture was therefore being slowly abandoned or modified due to geological phenomena.

Figure 7.10: Mixed Adobe and Corrugated Metal Walls

Another important and rather indigenous measure derived from the experiences of the 1841 and 1910 earthquakes relates to the erection of *tembloreras*. The temblorera was a room built with wooden walls that was added to an adobe or a bahareque house, typically in the back garden. In times of seismic activity, families would move into this “earthquake-proof” room. This measure, however, protected them mainly against aftershocks and provided little protection from the initial shock.

From 1910 to the 1950s, wood became a very popular building material. Wood is highly resilient in the event of earthquakes, although in a country averaging a 90% humidity level fighting decay proves problematic. Nowadays, houses are constructed mostly of reinforced concrete masonry or pre-cast concrete panels roofed with corrugated metal sheets. Wood is reserved for floors, doors and doorframes due to its high cost. This type of construction system is widely used for four main reasons:

- Concrete is a long-lasting material
- Concrete offers security against burglary (dry-wall boards, wooden or corrugated metal walls are easy to disassemble)
- Concrete walls can be flood-proof if plastered adequately
- Reinforced concrete is good at withstanding earthquakes

Figure 7.11: Typical Reinforced Concrete Residential Construction

From the historical analysis of events and measures, it can be concluded that in terms of building vulnerability to earthquakes, it has taken Cartago nearly 500 years to return to square one. During pre-colonial days, both the choice of materials as well as the construction system guaranteed that buildings were highly resistant to earthquakes. With the arrival of the Spaniards and the adoption of traditional Spanish architecture (adobe walls and heavy clay tile roofs), the building stock became highly vulnerable. A slow and painstaking process of evolution then took place over a period of 150 years, starting with Braulio Carrillo’s decrees of 1841. Buildings currently being constructed are highly resistant to earthquakes, although the materials and techniques used differ from those used by native people 500 years ago. Figure 7.12 graphically depicts the evolution of building vulnerability to earthquakes in Cartago.

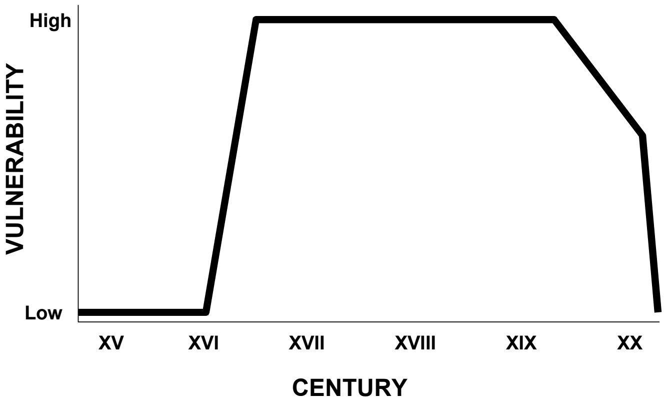


Figure 7.12: Evolution of Building Vulnerability in Cartago throughout its History (conceptual)

7.3 HUMAN PERCEPTION OF DISASTERS

Human perception of hazards is extremely important in urban disaster management as it allows the selection of measures that will be accepted and therefore complied with by the community. In Cartago, there are two written accounts that give an insight into the changes in relation to human perception of hazards that have taken place. The first account is known as the “Iztarú Legend” and it is important because it gives an insight into the human perception of hazards before the arrival of the Spanish. The Guarco Valley was in those days inhabited by two main groups, one located in the northern part of the valley and ruled by Cacique Coo, while the other one was located in the southern part of the valley and was ruled by Cacique Guarco. It must be noted that this legend dates back to shortly before the arrival of the Spaniards, as it is known that Juan Vázquez de Coronado met Cacique Guarco. Coo and Guarco were engaged in a fight for supremacy over the valley. Guarco slowly gained territory from Coo. When Coo died, Aquitaba succeeded him. Aquitaba was a strong fighter but, when faced with the loss of considerable ground to Guarco, he took his daughter Iztarú to the highest mountain in the northern part of the region and had her sacrificed to the gods in return for triumph in war. Shortly after, during a fierce battle, Aquitaba implored aid from the sacrificed Iztarú. Legend has it that Aquitaba’s plea resulted in fire, ashes and rocks that came down the mountain, forcing Guarco’s fighters to flee. Furthermore, from one side of the mountain “a river of hot water” (probably a lahar) came down and destroyed Guarco’s village. Alvarado et al. (in Peraldo and Montero 1994) consider the natural event described in this legend to be true as Spaniards refer to arriving at the “valley of desolation”, a valley covered by ashes and trees without foliage. According to Peraldo and Montero (1994), it would appear that this legend was documented by Spaniards who heard it first hand from Cacique Guarco.

The second story is a written account dating back to colonial days that clearly describes how people raised in the Spanish traditions and beliefs perceived natural events. The account relates to a description of the damage caused by an “earth tremor” that took place in July of 1746 and was documented by an inhabitant of Cartago in the archives of the Church of Our Lady of Los Angeles. The witness describes the earthquake as taking place between two and three o’clock in the afternoon and lasting around four minutes. Following the description of the tremor, he makes a very interesting remark related to the cause of the earthquake: “earthquakes of that sort are signs of divine indignation and are very well deserved punishment for our enormous sins”.

According to La Prensa (2001), in 2001 70.3% of the population still viewed themselves as belonging to the Catholic Church, although there has been a sharp decline in mass attendance and a tendency towards a decrease in the number of “believers” (in 1995 the figure was 84%). There are many who still view disasters as a divine punishment. Therefore this perception of natural disasters as an “Act of God” should be a consideration in disaster mitigation strategy formulation. Moreover, Cartago is the religious centre in Costa Rica due to the “Legend of La Negrita”. This tells of a statue of the Virgin Mary that appeared and re-appeared many times to a native woman in the Puebla de los Pardos (the part of town reserved for the natives) during early colonial days. Since then, every year on the eve of the 2nd of August around half a million people (approximately one in eight Costa Ricans) make the pilgrimage to the Church of Our Lady of Los Angeles in Cartago.

7.4 NATURAL HAZARDS

In summary, Cartago lies on relatively flat land (refer to digital elevation model in Figure 7.14) and suffers from both hydro-meteorological and geological hazards. However, although earthquakes have definitely caused greater loss of human life and property losses within its urban area throughout history, one of the most interesting issues relates to the various triggering effects that occur in Cartago (refer to Figure 7.13). For this reason, it is difficult to describe these phenomena individually. The following sections attempt to explain the natural phenomena that pose a threat to Cartago, although the risk assessment to be carried out in Chapter Eight focuses on earthquakes only.

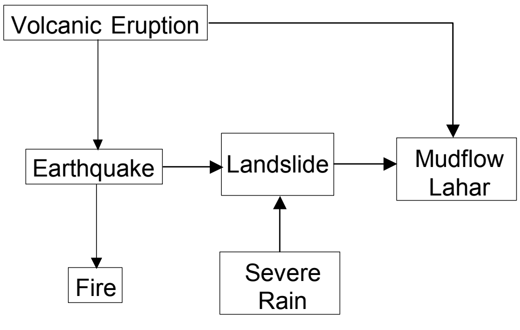


Figure 7.13: Triggering Effects of Natural Phenomena in Cartago

The most important river in Cartago is the Reventado River, which under normal conditions carries such a small quantity of water that it can hardly be referred to as a “river”. This river originates near the crater of the Irazú volcano and crosses the city from north to south. Figure 7.15 illustrates the river network in relation to the built-up areas, based on photo interpretation of scale 1:20,000 aerial photographs dating from the year 1998.

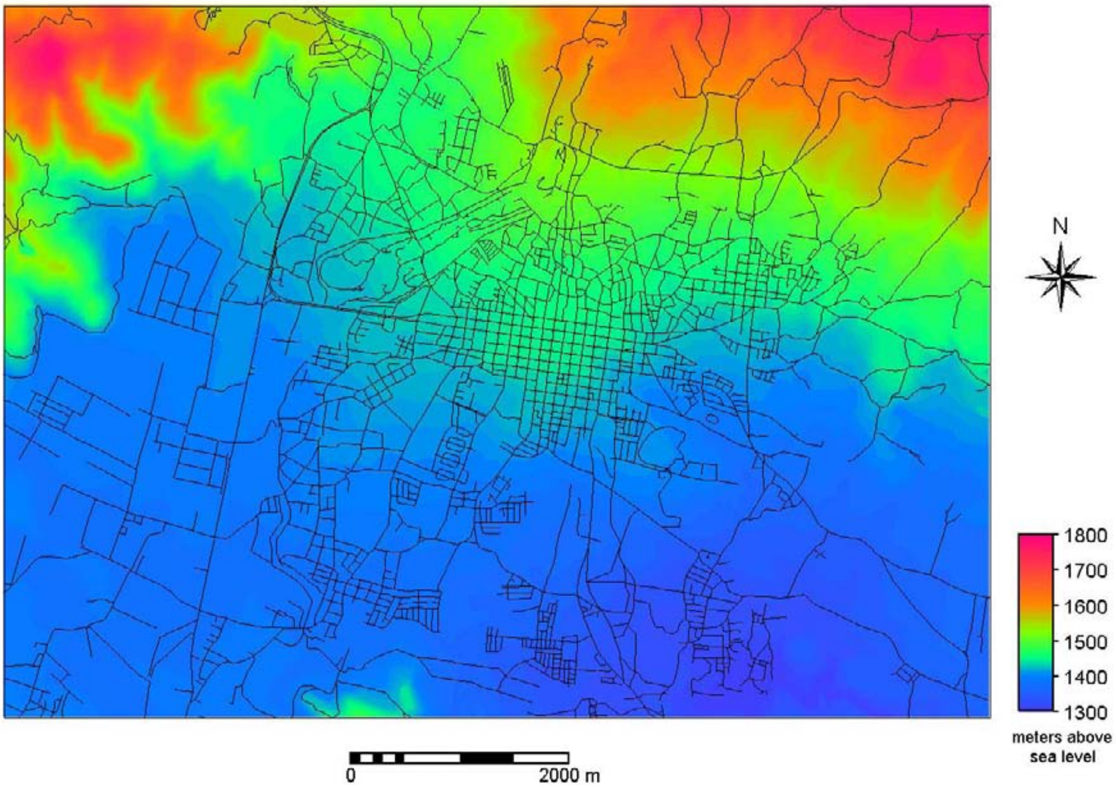


Figure 7.14: Digital Elevation Model

Although some flooding occurs, Cartago does not suffer from severe floods despite annual precipitation of around 2,400 mm. The National Emergency Commission for the Prevention of Risks and Response to Emergencies (CNE) considers, however, that the recurrence of these floods in this area has increased due to several factors:

- Development carried out in the floodplains
- Disorganised and unplanned urban development
- Lack of compliance with urban and forestry laws
- Deforestation along the river basins
- Decrease in the hydraulic capacity of the basins due to dumping of solid waste

Cartago is located in one of the most seismically active regions in the country. An important fault system located 3 km from the city (see Figure 7.15) is thought to be responsible for shallow earthquakes that devastated the city both in 1841 and 1910.

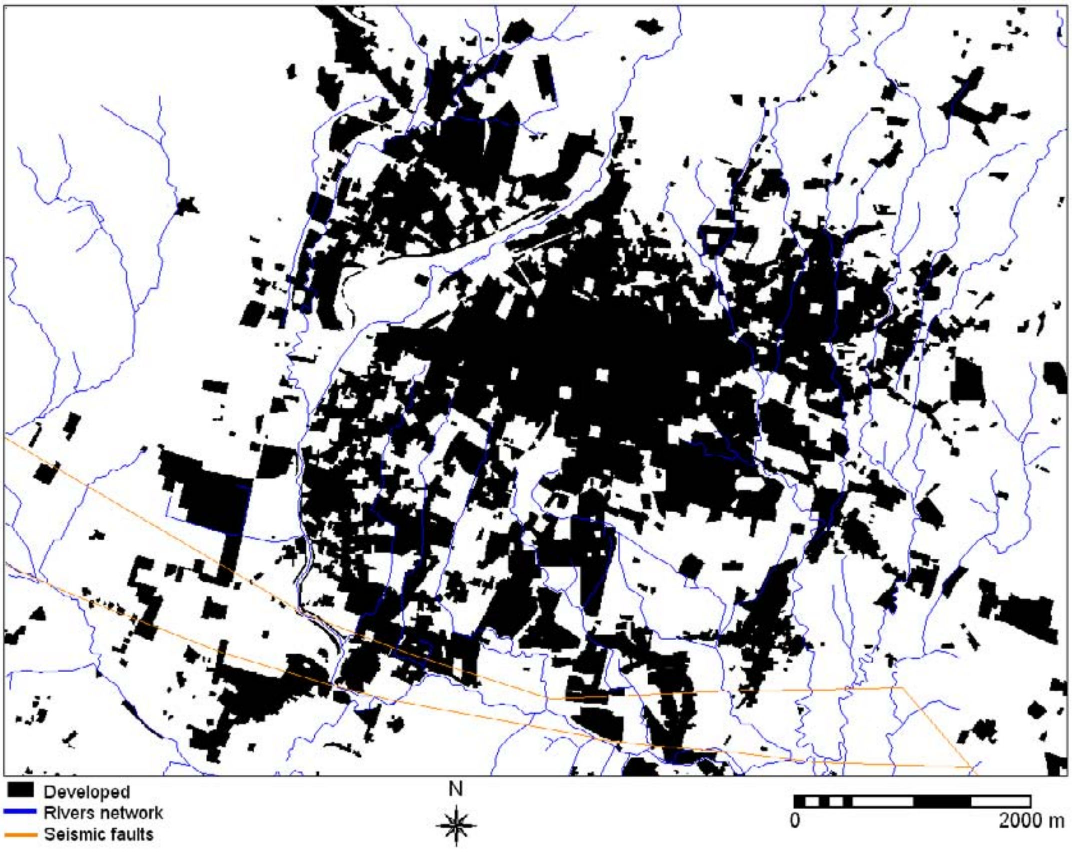


Figure 7.15: Seismic Faults and River Network in Cartago

The Irazú volcano is one of the most active volcanoes in the Central Valley. It has caused earth tremors that could be felt in Cartago. Historical records confirm volcanic activity in 1724, 1917, 1918, 1919, 1924, 1933, 1939, 1940, 1961, 1963 and 1965 (Comisión Nacional de Prevención de Riesgos y Atención de Emergencias (CNE) 2002). It is estimated that the last time that Irazú erupted lava was around 14,000 years ago. In fact, some scientists argue that the 1910 earthquake was not caused by a sudden release of energy from the Coris, Guarco and Agua Caliente Faults but that the earthquake was actually caused by the volcano's activity.

According to CNE, the following are the expected effects that a seismic event could cause in Cartago:

- Seismic amplifications in the city of Cartago and surrounding areas where soil is silty (limoso) or not well compacted
- Landslides such as the one at San Blas, which could block river basins and trigger mudflows into the city
- Ground rupture
- Ground settling in those areas that have been improperly infilled

Figure 7.16 depicts the expected peak ground accelerations (PGA) for Cartago, represented as percentages, according to research by Flores and Schmidt (2000).

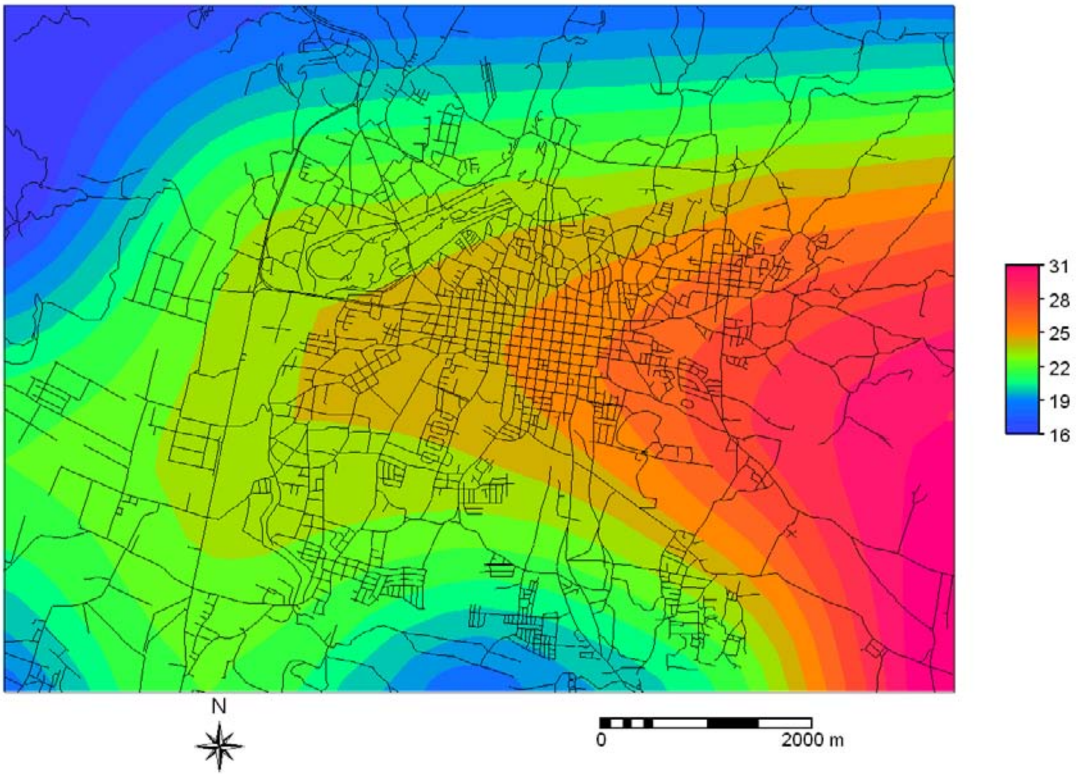


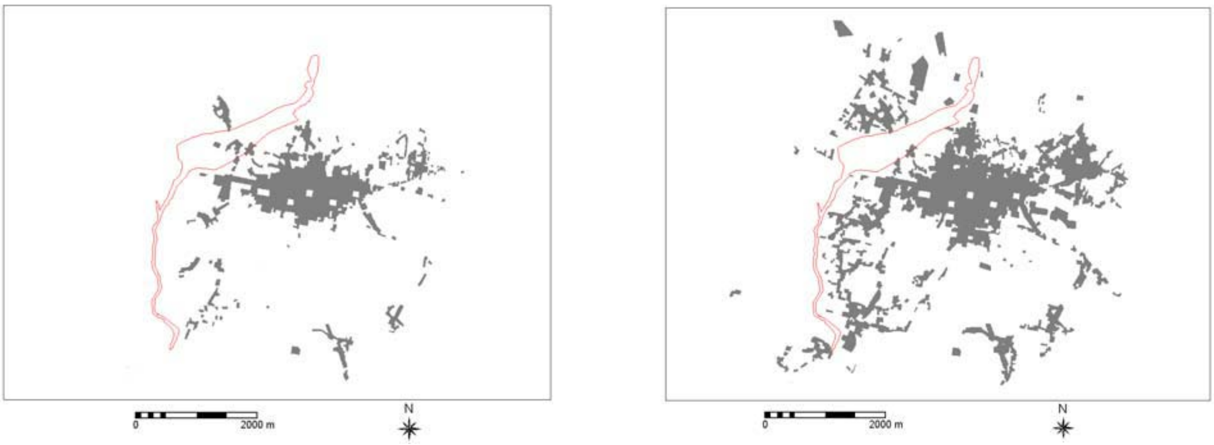
Figure 7.16: Peak Ground Acceleration (source: Flores and Schmidt 2000)
Note: The original source was in the form of contour lines.

The city has been washed away by lahars (mudflows of volcanic origin) several times throughout its history as the river basin has become blocked by ash thrown into the air by the Irazú volcano. The last lahar event occurred in 1963 and claimed the lives of 23 people. Lahars along the basin of the Reventado River could bury and wash away the infrastructure that is located alongside the basin (e.g. RECOPE oil duct, electric mainlines, several rail bridges, Orosí aqueduct), as well as an industrial area and human settlements. Cartago's soil characteristics indicate these lahar deposits and, according to senior experts from the School of Geology at the University of Costa Rica, one of the major concerns is the possibility of liquefaction (settling of the terrain) caused by badly compacted ashes, which could cause considerable damage to buildings. Ash-falls could cause the collapse of weak roof structures, although due to the north-easterly direction of the prevailing wind, this would tend to affect San José considerably more than the city of Cartago. Gas emissions could affect the population as well as farming activities (both agriculture and livestock).

The San Blas landslide (only 1.5 km. north of the centre of Cartago) is one of the most important landslides in the Central Valley. It is caused by three factors: a steep terrain characterised by badly compacted soil and its location in an area suffering from high precipitation. This landslide poses a direct threat to agricultural land and an indirect threat to urban areas, since the Reventado River lies at its foot slopes. If the river basin became blocked by debris from the landslide, a mudflow could be triggered and could seriously damage vital and costly infrastructure along the river basin. Possible effects caused by landslides in Cartago include the destruction of roads and houses and damage to farming land in its urban fringe, as well as the triggering of mudflows due to the blocking of river basins. Landslides are also likely to take place in areas where slopes have been modified through quarrying or for building roads. This is not likely to affect the urban area but rather the urban fringe to the north of Cartago where the terrain is hilly. Recently, CNE installed an early warning system on the Reventado River.

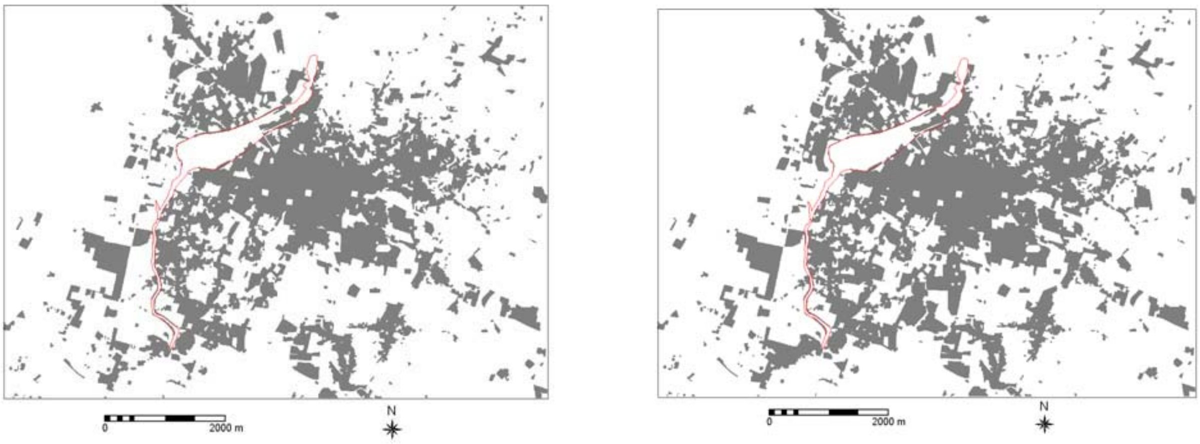
Figure 7.17: Squatter Occupation of the Floodplain
inside the Perimeter of the Reventado River Dyke

One important issue relates to the squatter occupation of both the floodplain of the Reventado River and the area within the perimeter of the dyke itself. This dyke was built in response to the casualties of the 1963 lahar. Note that in Figure 7.18 a gap in urban growth appears where development existed in 1945. This area was cleared after the 1963 lahar event and families were relocated. A dyke was built shortly after but the 1989 growth map shows some development inside this area. As Figure 7.17 illustrates, this development is in the form of squatter settlements. Despite several relocations carried out by the authorities, squatter settlements keep sprouting up in that location as word has spread that due to the hazard level of the area, families that settle there are given access to land and subsidised housing more rapidly than elsewhere in the Central Valley. The construction of the dyke itself has been questioned in terms of its adequacy and maintenance levels, although an early warning system has been put in place upstream to provide some alert to the authorities and the families which live within its perimeter.



Year 1945

Year 1974



Year 1989

Year 1998

Figure 7.18: Urban Growth of Cartago
(The mapping was carried out based on vertical survey photographs and small format oblique photographs. The red line illustrates the perimeter of the dyke constructed in the 1960s to protect the city from future lahars.)

CNE has issued recommendations for urban development in Cartago, particularly with respect to floods and earthquakes. The recommendations regarding flood hazards include the following:

- The Municipality of Cartago should not allow urban development in the floodplains and should request any person wishing to obtain a building permit in these areas to obtain clearance first with the Fluvial Department of the Ministry of Public Works as well as with the Forestry Department of the Ministry of Agriculture.
- Promote awareness campaigns to avoid contamination of the rivers and the dumping of solid waste, and establish community work in the field of basin cleaning and maintenance.
- Plan proper neighbourhood drainage schemes for rain and sewage water.
- The municipality should encourage the participation of other government institutions, the private sector, non-governmental organisations (NGOs), community-based organisations (CBOs) and the population itself in the cleaning and maintenance activities.

- Groups should be organised to carry out periodic monitoring of the basins near populated areas in order to prevent the population being surprised by unexpected flash floods and lahars.

The CNE recommendations for urban development in the field of seismic risk prevention include:

- Prevent the issuing of construction permits for steep terrain. This should be extended to those areas that have a history of soil instability.
- Follow up on construction permits to intervene in those cases where construction materials or practices prove to be unsuitable.
- Control of permits for landfills which usually do not meet the adequate conditions.
- Avoid the issue of building permits for areas specified under the "Decree of the Reventado River" or located very close to the river basins that have had avalanche occurrence.
- Give special consideration to community infrastructure (e.g. solid waste sites, aqueducts, roads) in terms of their planning and design.

7.5 AVAILABLE DATASETS

This section will first analyse data produced by government institutions from the point of view of urban disaster management. Next, the use of data to support the planning process in Cartago will be reviewed.

7.5.1 National Housing and Population Census

The National Housing and Population Census is carried out every 10 years by the National Statistics and Census Institute (INEC) – although the Ministry of Education is heavily involved since schoolteachers carry out the actual surveying. Information is collected at household level but data is aggregated at the census tract level.

An analysis of census tracts throughout the world reveals that the concept of "census tract" varies slightly. In Costa Rica, a census tract is a spatial unit that groups approximately 40 houses in urban areas and around 60 houses in rural areas. The boundaries of the census tract are modified when the number of houses has increased or decreased above or below the threshold. Unfortunately, this change in the spatial boundary somewhat limits the use of this dataset for analysing changes. The shape of the census tract units tends to be very irregular and there seem to be no guidelines for defining the shape (see Figure 7.19). Census tracts can be aggregated at the district level, a unit that very seldom changes its boundaries, although its size limits its suitability for most types of urban analysis. Due to their characteristics and sizes, it could be argued that the district level is adequate for metropolitan (big urban) planning, whereas the census tract is suitable for urban planning but not adequate for neighbourhood planning.

Despite a controversial application of a confidentiality law that currently causes access to the census tract level dataset to be denied, it is important to review this dataset as there is considerable scope for mapping relevant themes. Moreover, the issue of denial of access to this dataset might change in the near future, as government institutions consider that this case can be legally contested on the grounds of misinterpretation of the law. Several important themes contained in this census could be used in combination with the risk zonation process. This data integration to guide decision-making will be discussed in detail in this chapter and Chapter Eight.

In terms of data format, the attribute data is entered into a digital database. The maps containing the boundaries of the census tracts are in analogue format. It is considered feasible for municipalities to digitise these polygons as this activity is not time-consuming and does not require highly qualified staff.

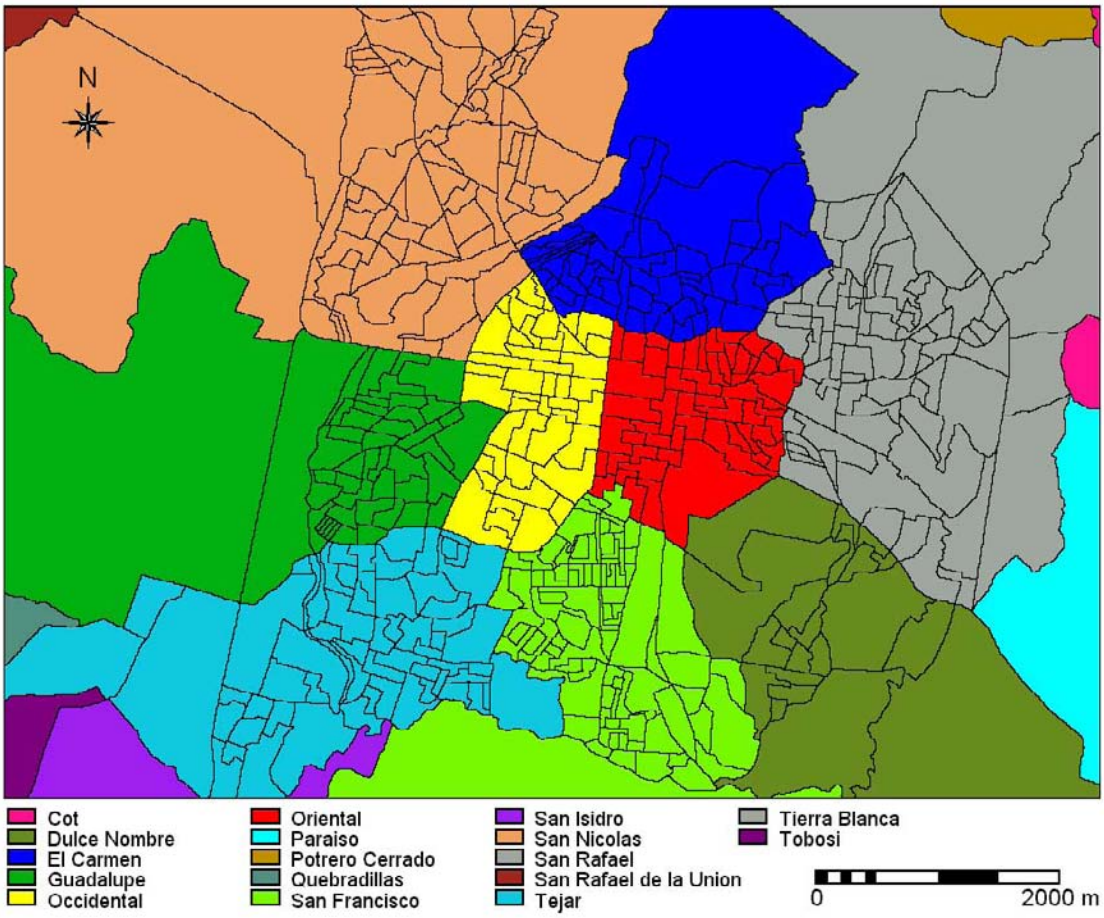


Figure 7.19: Aggregation of Census Tracts to District Level

7.5.2 Hazard Mapping

As discussed in Chapter Five, it is the responsibility of CNE to map hazard areas, to inform each local government of these hazards and to provide basic guidelines.

One of the biggest drawbacks identified relates to the type of mapping available at CNE. Most of the maps are produced at 1:50,000 scale, which is unsuitable for urban planning. On the other hand, the maps produced in most cases cannot be described as hazard zonation but rather as geological or geomorphological maps.

The biggest problem relates to the seismicity of Cartago, as its “hazard map” includes the fault lines and location of historical earthquakes instead of a micro-zonation with either PGA or intensity values. This information is unsuitable as it has little to offer an urban planner.

7.5.3 Municipal Cadastre and Strategic Plan

The National Cadastre in Costa Rica is presently undergoing decentralisation. According to its plan, the central cadastre should be transformed into modern multi-functional municipal cadastres that can be used for a number of activities such as urban development, infrastructure planning, agrarian reform, tourism development, natural resource conservation, improved land-use and improved revenue collection. In general, the data collected contains basic details of:

- The owner (name, national ID number, phone, fax, address)
- The parcel (parcel ID, location, area in square metres, land-use)
- Building permits (e.g. date, value of construction)
- Taxes (e.g. water, solid waste, sidewalk, sewerage)

It is rather doubtful, however, whether the goal of a multi-functional cadastre can be achieved using the attribute information that is being collected by the Cadastre Department of the Municipality of Cartago. It would therefore appear that due to financial limitations the local government is focusing on revenue collection.

The Municipality of Cartago is presently digitising parcels and entering basic attribute information in a database. At the time of the last visit (in July 2000), it was their view that the biggest difficulty in the analogue-to-digital conversion of the cadastre was computer hardware and human resource allocation.

Despite a relatively coherent regulatory framework and in a highly hazard-prone area such as Cartago, it is unfortunate that little hazard-related information is being used for granting or denying building permits. The strategic plan for Cartago produced by the National Housing and Urbanism Institute (INVU) in 1974 has not been updated and it is presently being overlooked as it is obsolete. On the other hand, the National Emergency Commission for the Prevention of Risks and Response to Emergencies (CNE) supplied the municipality with a “hazard atlas” which is unsuitable from the point of view of both the information contained and the scale.

7.5.4 The National Geographic Institute (IGN)

The National Geographic Institute produces aerial survey photographs (large format) on average every 10 years. The photographs taken of urban areas are usually at scales of either 1:20,000 or 1:30,000. The institute also produces 1:50,000 topographic map sheets which are periodically updated in the case of urban areas, but in the case of rural areas can be as much as 30 years old.

Regarding higher resolution base mapping, a very good 1:10,000 topographic and land-use map was produced in 1991 (but only for the Central Valley). However, at this moment it seems uncertain whether this series will be continued as the institute is unfortunately very poorly funded. The classification of land-uses in this series (see Table 7.1) is very extensive and it therefore constitutes a very important dataset for urban land-use and disaster planning.

a. Residential i. Residential elderly ii. Residential higher density iii. Residential special iv. Other residential	**b. Industrial** i. Agro-industrial ii. Other industrial **c. Commercial**
d. Institutional i. Banks ii. Cemetery iii. Hospital iv. Clinic v. Community hall vi. Fire brigade vii. Town hall viii. Jail ix. Police x. Library xi. Infrastructural xii. Religious xiii. Red Cross	**e. Recreational** **f. Education** i. Education primary ii. Education secondary iii. Education higher **g. Other** i. Forest ii. Forest non-primary iii. Greenhouse iv. In process of urbanisation v. Wetland vi. Agricultural vii. Vacant

Table 7.1: Classification of Land-Uses in 1991 Land-Use Mapping

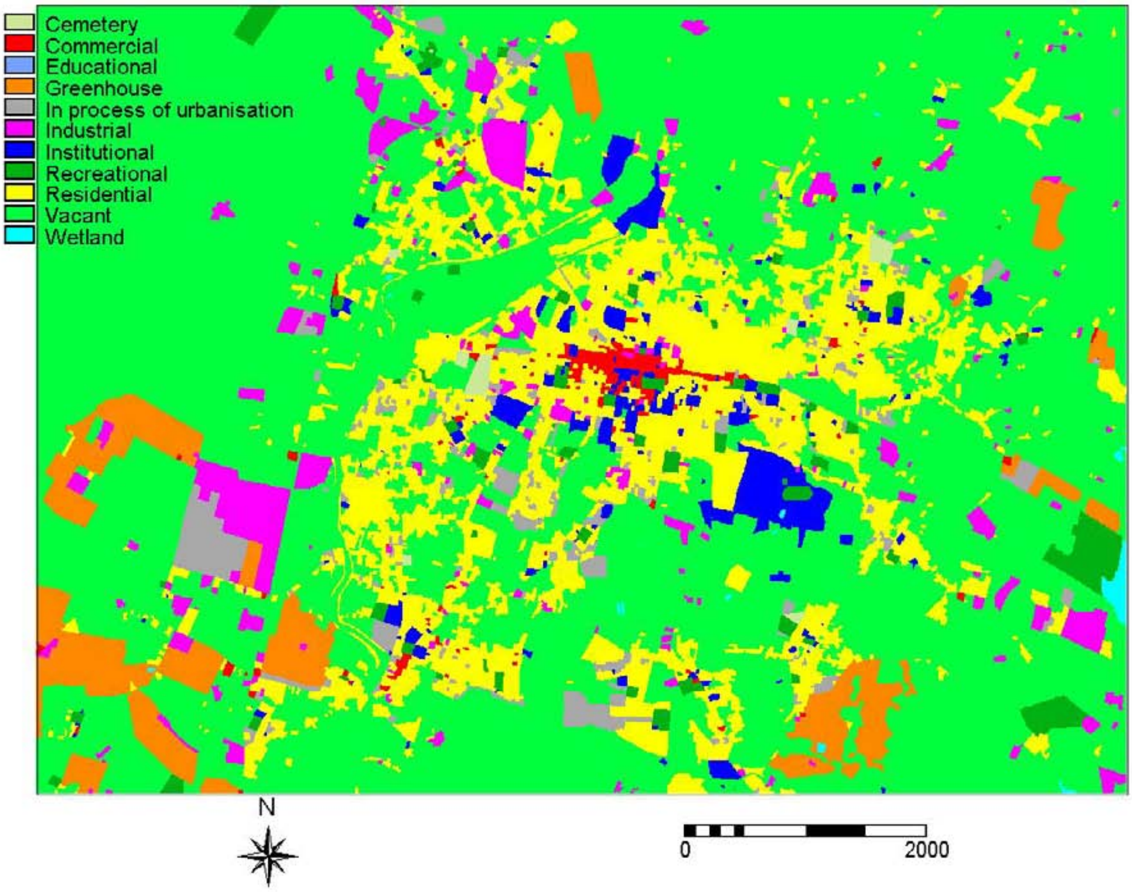


Figure 7.20: Land-Use Map Based on 1991 Analogue 1:10,000 Sheet (digitised from IGN map)

7.5.5 The National Insurance Institute (INS)

During the late seventies, the National Insurance Institute contracted a team headed by Franz Sauter, the country's leading structural engineer (and co-author of the National Seismic Code), to prepare a method for estimating earthquake insurance premiums. Sauter developed his own attenuation function for converting the PGA values into Modified Mercalli Intensity (MMI) values (refer to Chapter Three). As part of this research, Sauter's group developed vulnerability curves (refer to Figure 7.21) given in MMI values. The curves represent a very valuable damage dataset despite two weaknesses:

- The curves have been developed on the basis of building type without considering the building height parameter.
- The curves only provide a mean damage ratio rather than being subdivided into damage severity levels. This is particularly relevant for the purpose of casualty estimation as casualties tend to occur in heavily damaged buildings.

The other relevant dataset this author developed is the earthquake probability for the most important cities in the country. Earthquake probabilities for Cartago are presented in Figure 7.22.

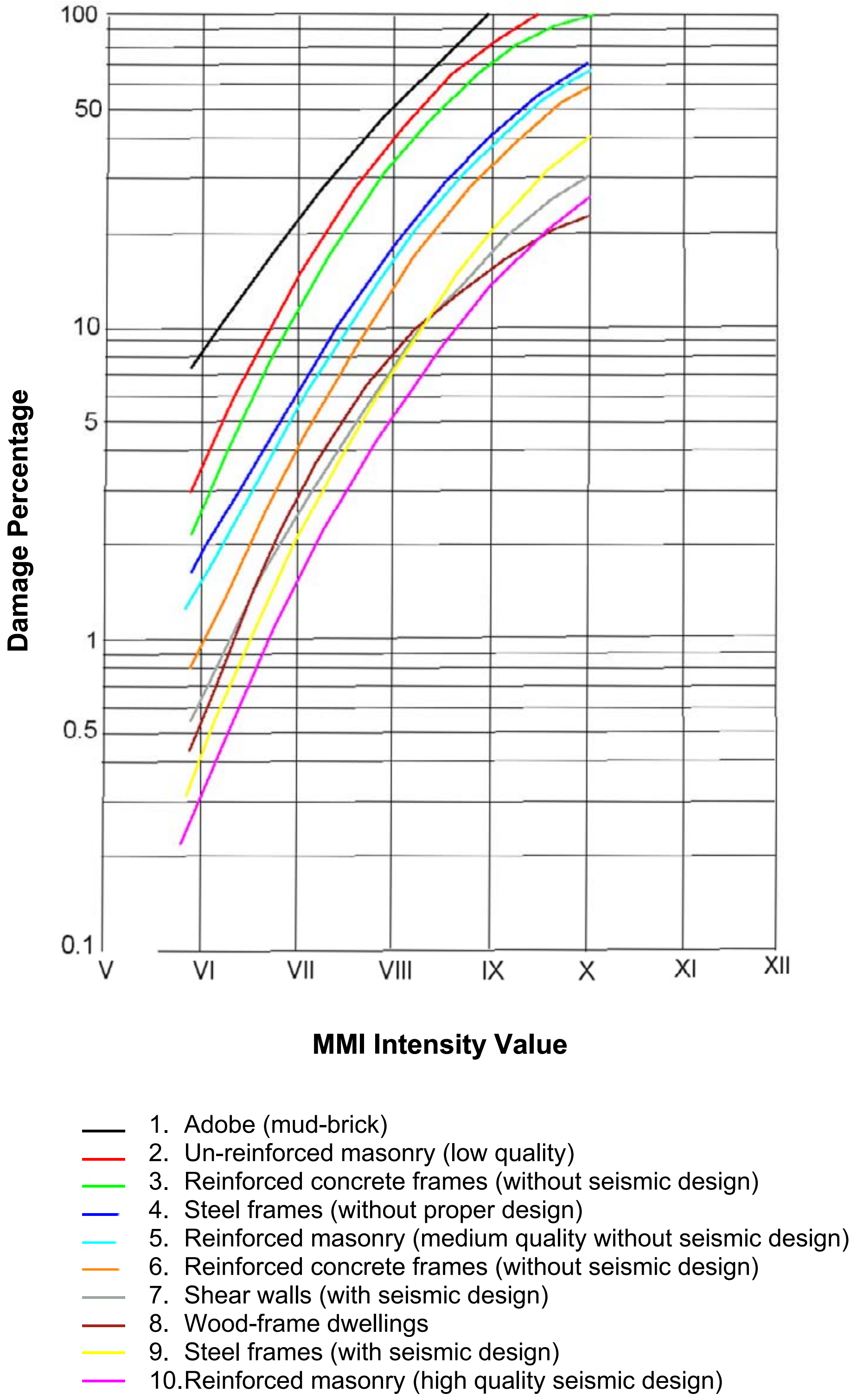


Figure 7.21: Vulnerability Curves for Costa Rica (Sauter and Shah, 1978)

7.5.6 Other Institutions

The School of Geology of the University of Costa Rica in San José produces hazard zonations, although they only carry this out in selected areas and for academic purposes.

The scale of such studies is not appropriate for urban planning as these are being produced at 1:50,000 scale, although a zonation on mudflow zonation was found at 1:25,000 scale.

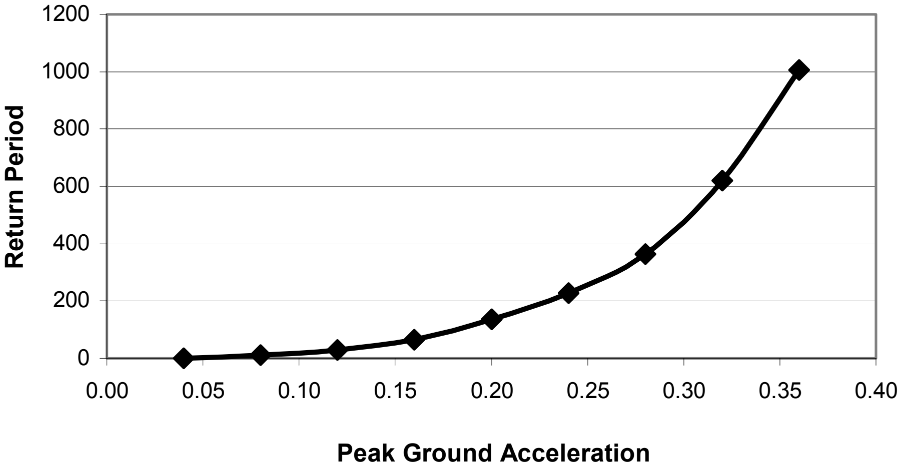


Figure 7.22: Earthquake Probability in Cartago (Sauter and Shah, 1978)

7.5.7 National Spatial Data Infrastructure Initiative

The PROCIG (Central American Project for Geographic Information) initiative constitutes the first regional initiative for setting up a spatial data infrastructure in Central America. In Costa Rica, IGN (the National Geographic Institute) has become actively involved since November 2000 and, along with personnel from CATIE (International Centre for Tropical Agriculture), has carried out a characterisation survey. This survey forms the basis for the development of a national geo-spatial data infrastructure. Twenty-one institutions that either develop or manage geographical information were interviewed. Although a considerable amount of work remains to be done, this constitutes an important step in setting up standards, encouraging the production of metadata and encouraging the exchange and dissemination of data.

7.6 CONCLUSIONS

The analysis of the historical evolution of the building stock in Cartago illustrated the serious consequences of rejecting indigenous building materials and practices. It was also concluded that awareness-raising and educational campaigns in Cartago should be designed taking into account both indigenous and religious views on natural phenomena. Given the limited baseline information available in Cartago and its spatial characteristics, it was concluded that the results of the risk assessment should not be presented to decision-makers at the parcel level. Data should therefore be aggregated to the census tract level to keep the uncertainties under control.

Chapter Eight: RISK IN CARTAGO'S URBAN PLANNING PROCESS

The present chapter presents the results of using remote sensing for the identification of essential buildings and homogeneous areas, the risk assessment results and finally the implications that these results have for the future urban planning and disaster management of Cartago. The last section illustrates how risk assessment is used for guiding future growth and for the redevelopment of built areas. Due to the limitations of available hazard information, the first three sections in this chapter were carried out based on the macro-zonation of the Great Metropolitan Area (GAM) performed by Morales and Aguilar (1993). In the last section, however, the study of Mortgat, Zsutty et al. (1977) was used as it was the only one available that provided various probability scenarios for this city. This study assigns an intensity value for the city as a whole and it therefore fails to recognise site effects. The data was used despite this limitation as it serves to demonstrate how the risk assessment results are transferred into a cost-benefit analysis of mitigation strategies. The next and last chapter in this dissertation presents the conclusions and recommendations for further research.

8.1 ESSENTIAL BUILDINGS

A land-use map showing essential buildings was created (see Figure 8.1) by reclassifying an existing land-use map into three classes:

- First-order buildings: the fire brigade, police station, jail, town hall, Red Cross, hospitals/clinics
- Second-order buildings: religious, educational, community hall
- Regular buildings: all other land-uses with the exception of wetlands, forest, agricultural fields or greenhouses, vacant land including that which is in the process of urbanisation

Type of Building	**Ground Floor Area** (in ha)	**No. of Buildings**	**Percentage**
Essential – first order	24	50	1.5
Essential – second order	97	96	6.0
Regular	1495	-	92.5
Total	1616		100.0

Table 8.1: Buildings Classified According to Relevance for Emergency Activities

From the reclassification of land-uses, it can be concluded that on approximately 7.5% of urban land in Cartago there are buildings that could be key in the rescue and relief phases of the disaster cycle; on the remaining 92.5% of urban land there are regular buildings. A total of 146 essential buildings were identified; 50 of the first and 96 of the second order. Size varies according to the type; first-order buildings have an average plot size of 0.50 ha while second-order buildings average 1 ha. According to the methodology described in the previous chapter, analytical assessment of building response would have to be conducted on 50 buildings, while extensive screening would be performed on 96 structures.

Given the technical and human resources available in the municipality, it seems unlikely that these detailed surveys could be carried out with local manpower. It would also seem unlikely that the local government could afford to contract private consultants to carry out these assessments, given the time that this would require and the consulting tariffs involved. The establishment of strategic links with key academic organisations could be the mechanism to make these assessments possible. Provided there is adequate guidance and supervision, these otherwise time-consuming and costly datasets could be generated. Undergraduate civil engineering students could provide cost-free labour for performing the extensive screening of second-order buildings as part of their practical assignments. Similarly, postgraduate structural engineering students could model the seismic response of first-order buildings as part of their thesis work. Regular buildings – which constitute the vast majority – could be surveyed by municipal inspectors and by undergraduate architectural engineers or construction technologists. The Instituto Tecnológico de Costa Rica (ITEC) could be a key player in making risk assessment possible since it is located in Cartago and it offers a graduate degree in construction technology.

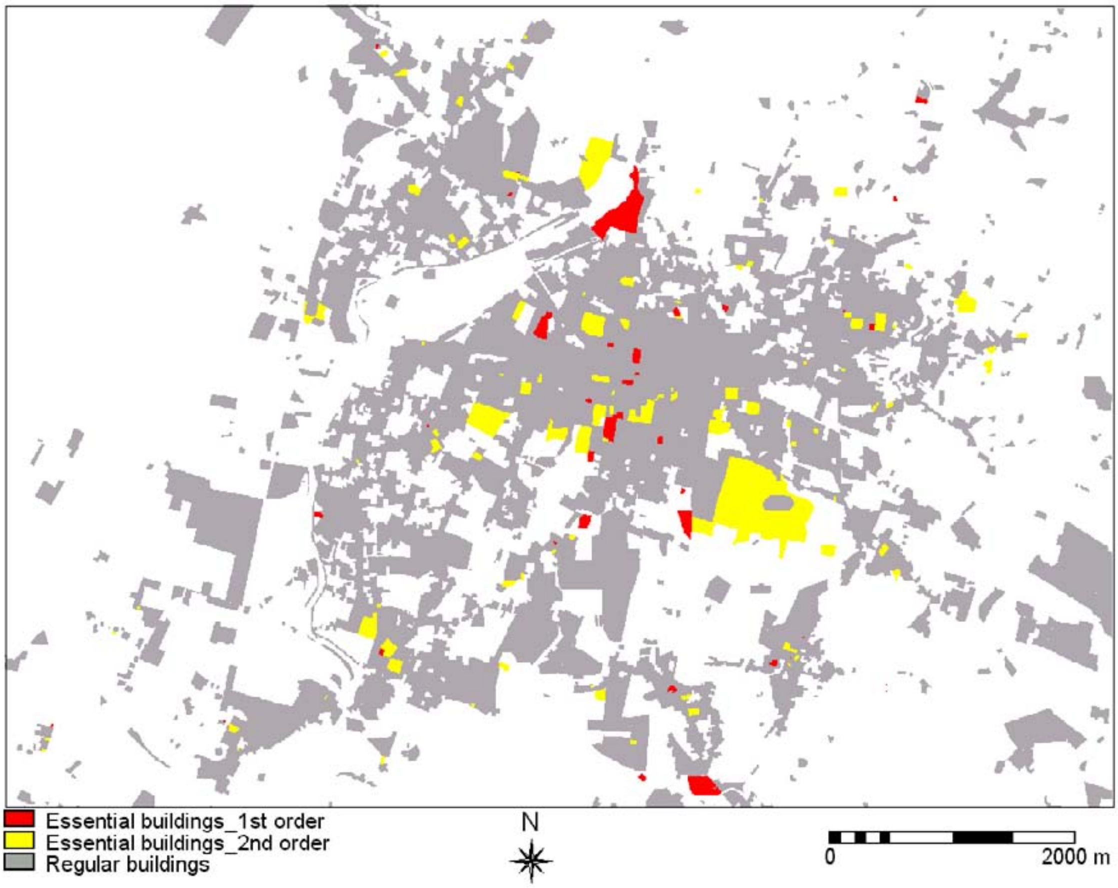


Figure 8.1: Distribution of Buildings According to their Importance for Emergency Operations

Essential buildings of the second order are those that have been identified as having potential as roofed temporary accommodation. Proximity to temporary accommodation is relevant from a pragmatic point of view, as fear of theft of house contents means most house owners refuse to move to temporary accommodation far from their parcels. This is a consideration that should not be overlooked by emergency planners as looting is a phenomenon that cannot be tackled by the police alone. Often limited police numbers dictate that guarding supermarkets and food warehouses takes priority over guarding residential areas.

Figure 8.2 gives an insight into the residential areas that are near potential roofed temporary accommodation. Due to time constraints and the relatively regular street layout of Cartago, buffers have been used, although network analysis (also referred to as “cost”) is the method that would provide the most accurate results. Of residential areas 21% are within 100 m of temporary accommodation while 9% are more than 500 m away. The alternatives for sheltering those who are too far away from roofed temporary accommodation are tents in open sports fields, squares or on vacant land. Such camps are only feasible if minimal facilities are either already available or can be rapidly set up (e.g. portable toilets, cistern tanks).

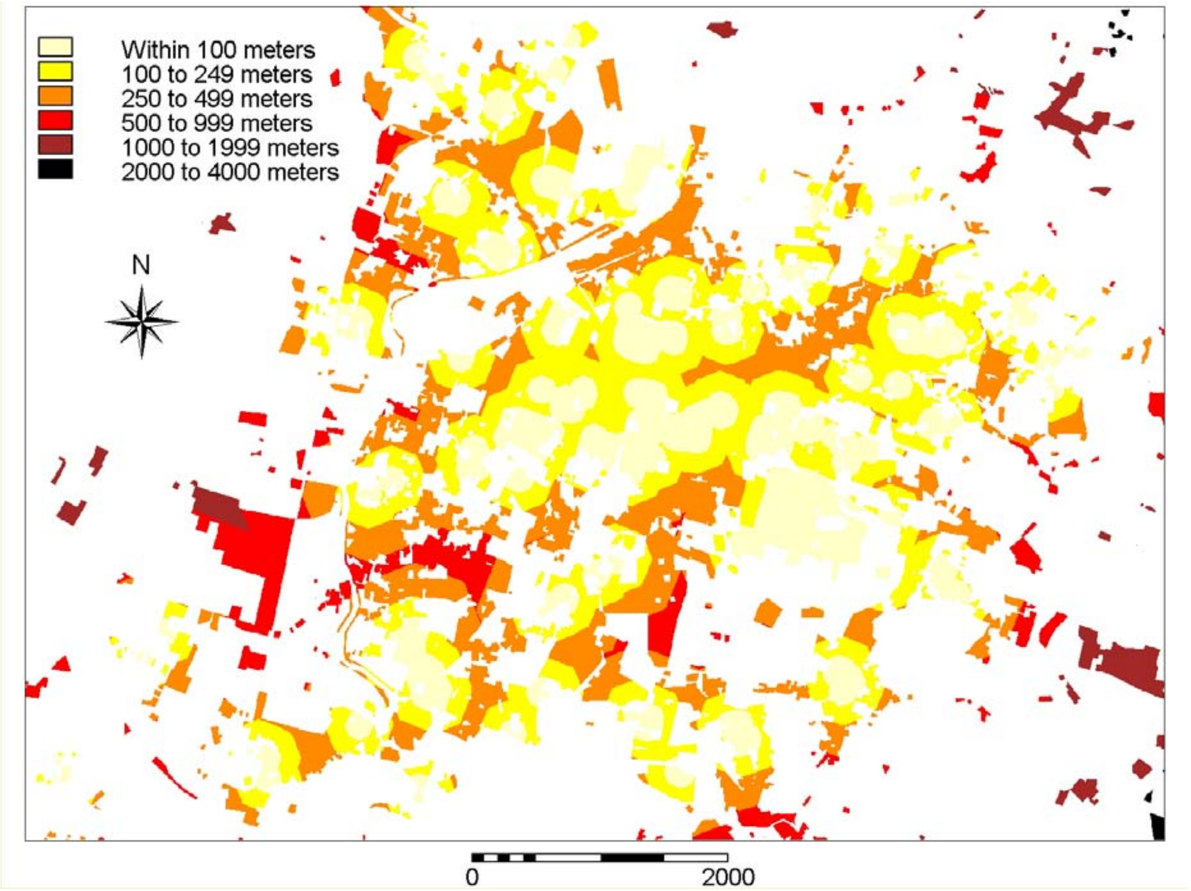


Figure 8.2: Proximity to Temporary Accommodation

Distance	Area	Percentage
Within 100 meters	231.9	21.10
100 to 249 meters	425.7	38.73
250 to 499 meters	347.3	31.60
500 to 999 meters	70.4	6.41
1000 to 1999 meters	22.5	2.05
2000 to 4000 meters	1.2	0.11

Table 8.2: Distance from House to Temporary Roofed Accommodation

8.2 HOMOGENEOUS AREAS

Since the most recent survey photographs available at the National Geographic Institute date from 1998, small format oblique photographs were produced with the aim of identifying recent development in the urban-rural fringes that had taken place between 1998 and 2001. An interpretation was carried out to identify the homogeneous areas (refer to Chapter Five) in order to quantify the human resources needed to carry out the ground survey.

Homogeneous Areas	**% of Homogeneous**	**Area** (in Ha)
Area No. 1	24.97	39.2
Area No. 2	11.02	17.3
Area No. 3	3.50	5.5
Area No. 4	20.19	31.7
Area No. 5	0.51	0.8
Area No. 6	0.57	0.9
Area No. 7	0.89	1.4
Area No. 8	5.41	8.5
Area No. 9	0.76	1.2
Area No. 10	0.76	1.2
Area No. 11	0.70	1.1
Area No. 12	0.96	1.5
Area No. 13	2.61	4.1
Area No. 14	1.85	2.9
Area No. 15	2.42	3.8
Area No. 16	1.97	3.1
Area No. 17	7.71	12.1
Area No. 18	13.18	20.7
Total	100.00	157.0

Table 8.3: Homogeneous Areas

Based on the interpretation of the aerial photographs it can be concluded that approximately 9% of the urban area can be classified as homogeneous. A total of 18 different areas were identified (refer to Figure 8.3), their sizes ranging between 1 and 39 ha (see Table 8.3), their average size being 9 ha. The areas are basically composed of three land-uses: industrial estates, low-income housing and squatter settlements. The largest of these areas is the industrial estate *Zona Franca,* which accounts for approximately 25% of homogeneous areas. This is one of several industrial estates built by the national government with the dual idea of attracting foreign investors and relocating existing industries from city centres to the outskirts of the main urban areas. Typically, buildings have been constructed using pre-cast concrete components produced by a single manufacturer. The case of low-income housing projects is very similar, as these are usually government projects which rely on prototype units built with either reinforced masonry or pre-cast concrete panels. Low-income housing based on pre-cast concrete panels has been the preferred method lately because of the guaranteed quality of the final product. Consequently, due to the uniformity within each of these areas, a single sample could be selected without compromising the interpretation accuracy of the results. Although the layout of the houses is not uniform in squatter settlements, the types of building materials used (e.g. corrugated sheets, wood) as well as construction techniques (wood-frames) are similar. In light of the extremely low vulnerability of wood-frame structures, these areas could be considered as homogeneous from a pragmatic point of view. Nevertheless, it is also important to map these areas as the high wood content and deficient electrical wiring mean they are likely to suffer from fire following an earthquake.

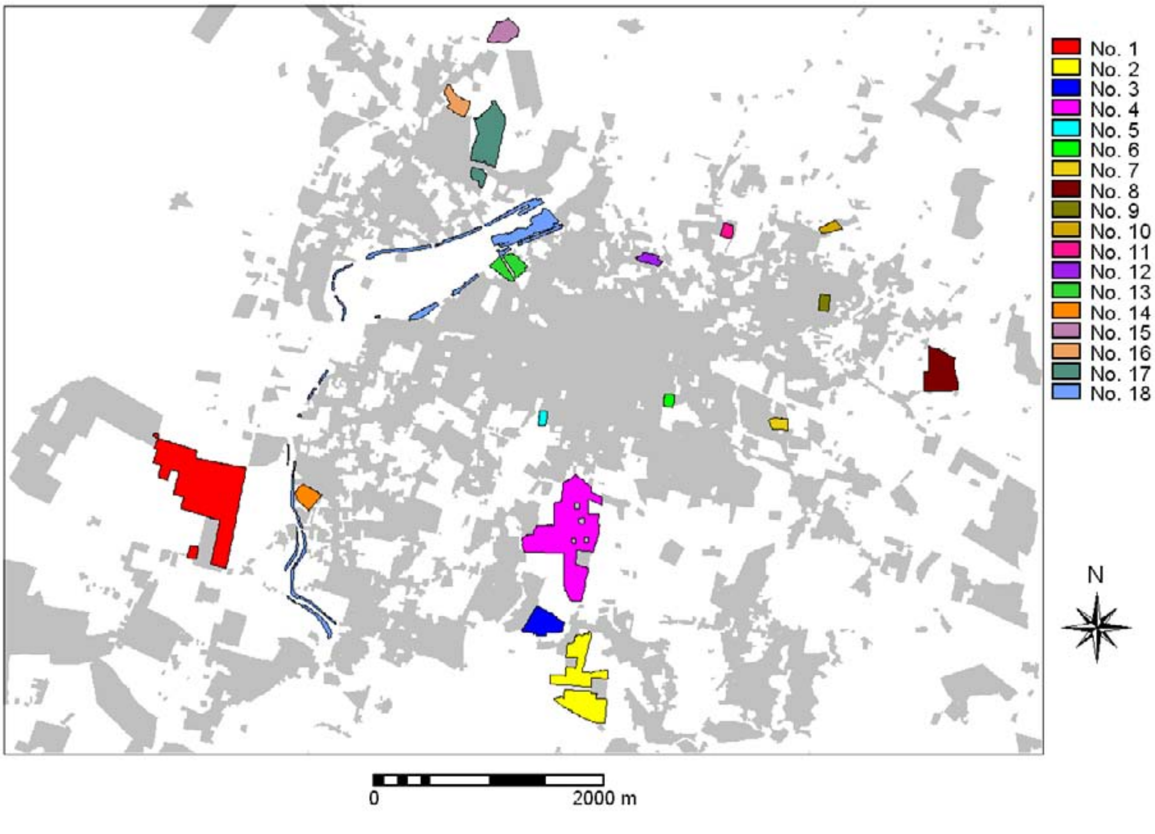


Figure 8.3: Identification of Homogeneous Non-Essential Built Areas

In Cartago, the standard block has an area of about 1 ha. A block contains approximately 25 plots averaging 400 m^2. A full ground survey implies a ratio of 25 buildings per ha while in homogeneous areas the ratio is only 0.12 buildings in need of survey per ha. Consequently, the delineation of uniform areas by means of remotely sensed images proved useful for cutting down on the number of buildings to be sampled by a factor of approximately 200. A full survey would involve approximately 41,000 buildings; however, by identifying the homogeneous areas and surveying only one building, nearly 4,000 buildings need not be surveyed. At five minutes per building, this implies a reduction of about 330 hours of ground survey time.

Elsewhere in the Central Valley, there has been a steady increase in the number of middle-income and high-income people who have chosen to buy or rent a housing unit in a condominium for security and cost reasons. Cartago, being the most conservative city in the region, has not experienced this phenomenon yet. This “condominium phenomenon”, however, is expected to reach Cartago in the near future. Consequently, it is soon expected that the percentage of urban homogeneous land will increase substantially.

It could be argued that local governments should actively promote the construction of industrial, commercial and residential estates. Housing estates are beneficial to both government and owners. From an owner’s point of view, estates represent a better deal as they offer increased security. Not only that, the cost per square metre of construction is lower due to two factors: a) optimisation in the use of labour and tools and b) discounts on building materials thanks to bulk purchases. From a local government’s point of view, the administration costs involved in issuing construction permits, inspecting the building process and periodically surveying for purposes of tax and risk estimation are lower for estates.

8.3 RISK ASSESSMENT RESULTS

8.3.1 Hazard Assessment

The analysis of the slope map highlights the relative flatness of the study area, as the mean slope is only 6.14 degrees. Moreover, 27.7% of the study area has no slope at all (0.00), while nearly 48% of it has slopes below 5 degrees (refer to Table 8.4). The highest slopes occur to the northwest of the city in La Carpintera, a protected wildlife area (refer to Figure 8. 4), and to the northeast.

Slope (in Degrees)	**Cumulative Percentage**
0.00	27.70
5.00	48.28
10.00	83.23
20.00	94.36

Table 8.4: Slope (in Degrees)

Apart from the relevance of contour lines for the assessment of local site effects (refer to Chapter Three), there is a regulation in the Construction Code that bans construction on slopes steeper than 25%. Construction should therefore be banned in approximately 10% of the study area (refer to Figure 8.4). Most of this land, however, is located within La Carpintera and since it is officially a "wild-life protected area", construction is banned and illegal occupation is highly unlikely as park rangers carry out systematic monitoring. Moreover, due to the lack of road access and the distance to "social infrastructure" (e.g. schools, clinics), this land is highly unattractive, even to the most dispossessed. Monitoring efforts by the municipal government to avoid illegal construction on steep land should therefore be concentrated on the northeast and south of the city.

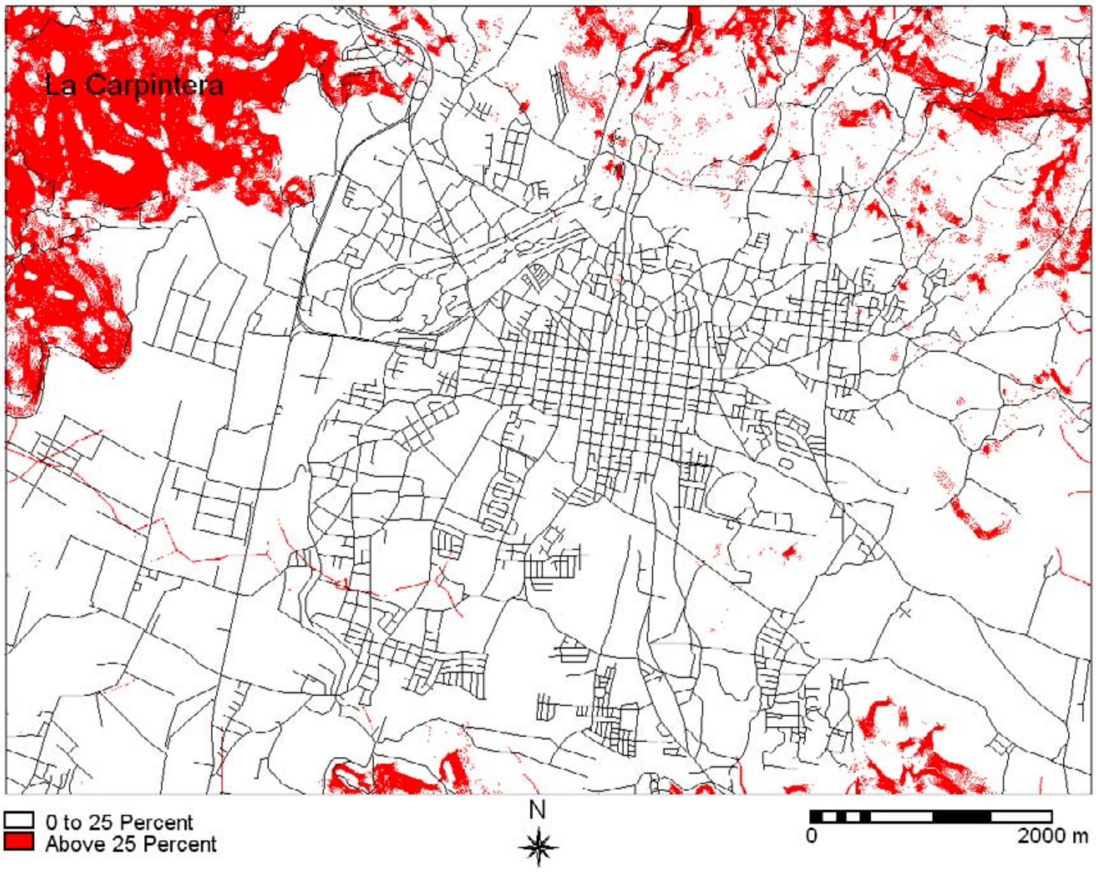


Figure 8.4: Regulation to Prevent Damage due to Landslides

According to the mapping developed by Morales and Aguilar (1993), the study area has the following ground shaking levels: 42% of the area (2,481 ha) falls under Modified Mercalli Intensity (MMI) VII while 58% (3,385 ha) falls under MMI VIII (refer to Figure 8.4). The hazard intensity scenario map was overlaid with the map depicting the urban and rural areas. In terms of the urban areas, 54% of the urbanised land falls under MMI VIII while 46% falls under MMI VII.

Contrary to popular belief, this study area is not considerably higher in intensity values than the rest of the Greater Metropolitan Area (GAM) (refer to Table 8.5). As can be observed in

Figure 8.5, the study of Morales and Aguilar (1993) on intensity levels in the GAM reveals that the higher values actually occur to the far west of this area, while Cartago lies in the far east. From the analysis of statistics generated from this map, it can be concluded that the median intensity in the GAM is VII while that of the study area is only one intensity level higher (VIII).

MMI Intensity Value	% Land in Study Area - Cartago	% GAM Land
VI	0.00	6.55
VII	42.30	63.23
VIII	57.70	26.12
IX	0.00	4.10
Median Intensity	VIII	VII

Table 8.5.: MMI Values in Study Area and in GAM

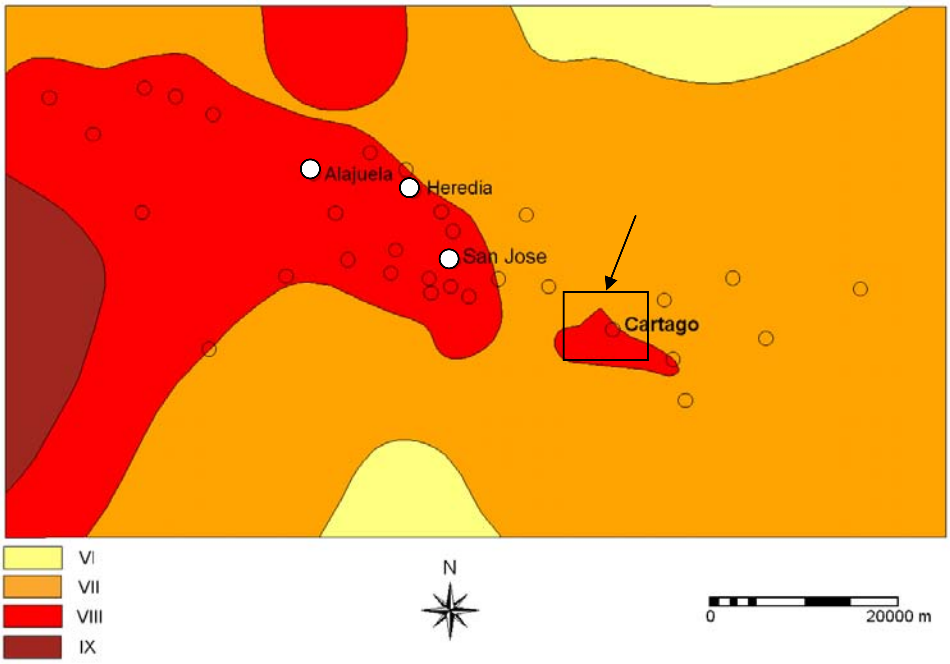


Figure 8.5. Map of Hazard Intensity Values of the Study Area

These figures highlight the problem of an incorrect perception of risk due to a lack of understanding of a) the difference between hazard and vulnerability, and b) hazard probability (return periods). The earthquake hazard alone is not to be blamed for the large losses suffered in Cartago (the last one in 1910), rather it is a problem of higher vulnerability. Property loss is generally due to the physical characteristics of the elements at risk while casualties have occurred either due to the buildings' vulnerability or poor education (e.g. relating to evacuation drills or safe areas).

This inaccurate perception of hazard levels in the Greater Metropolitan Area is by no means surprising. Except from the book *Geological Atlas of the Great Metropolitan Area* (which is readily available for purchase in bookshops), hazard zonation maps are not widely publicised in Costa Rica by the local government or by the National Emergency Commission (CNE). More diffusion of hazard zonation maps is needed, along with education of the population.

To avoid damage due to ground rupture, the Seismic Code explicitly bans construction within 50 m of active faults, although it fails to provide a definition of “active fault” or mention the institution that issues an official “fault map” to use for enforcement purposes. The School of Geology of the University of Costa Rica, after carrying out a comprehensive survey on the Coris and Guarco Faults in Cartago, issued a recommendation to avoid construction within 150 m of these active faults. Figure 8.6 illustrates the location of such buffers. Until very recently, however, this regulation could not be observed or enforced as there was controversy related to the location of these fault lines. Recently, after a field survey and mapping carried out by the School of Geology of the University of Costa Rica, the location of the fault lines was verified on the ground. This said, the Municipality of Cartago can issue a construction ban of this sort as part of a zonation map and this can only be properly enforced as long as an accurate digital map of these fault lines is available.

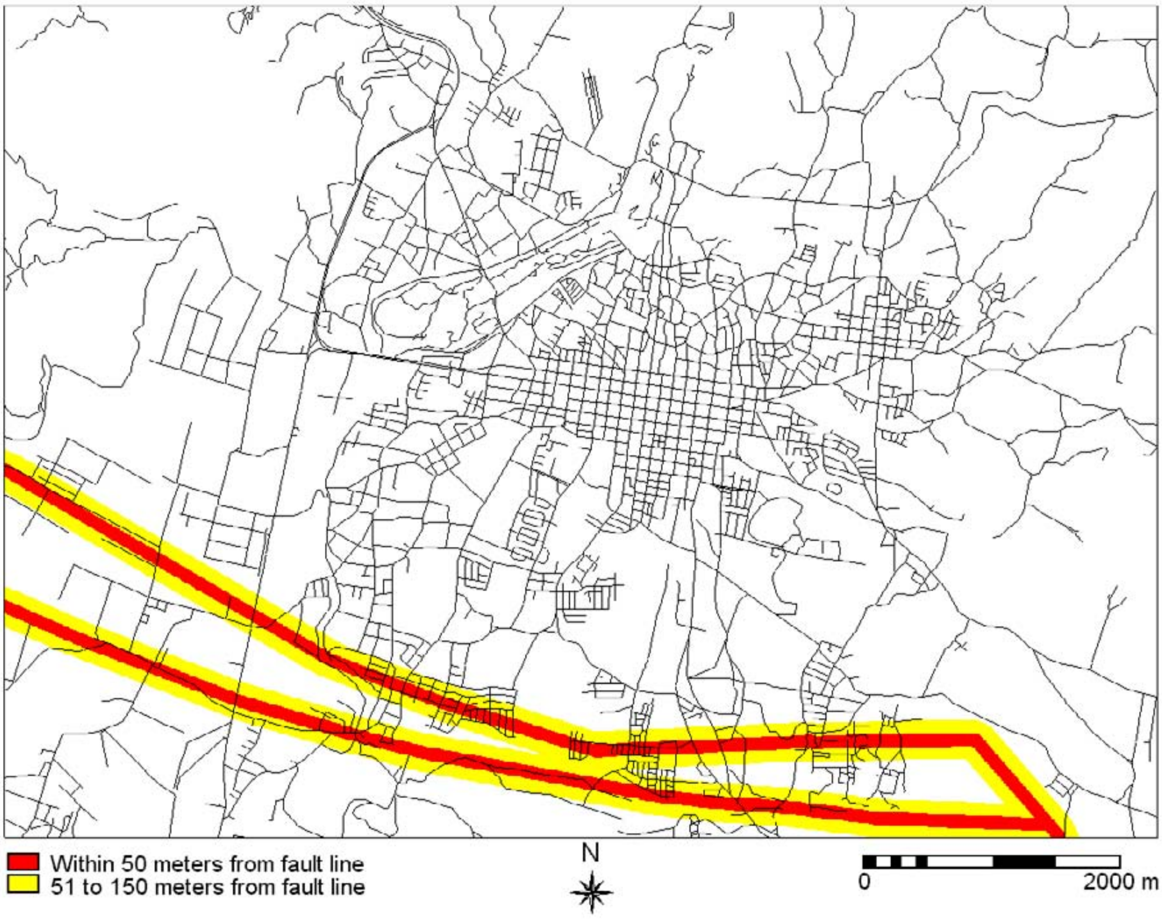


Figure 8.6: Regulations and Recommendations to Prevent Damage from Ground Rupture

The ban issued in the Seismic Code applies to 178 ha (3.03% of the study area), while the recommendation by the School of Geology applies to 339 ha (8.81% of the study area). Approximately 20% of the area under the ban is urbanised while 31% of the area under the recommendation has been developed. These figures at first seem disappointing but one must take into account that the ban was issued in 1986. An overlay of the buffer map with the growth map (refer to Figure 8.7) allows one to conclude that the rate of development inside this 50 m buffer area has decreased substantially since the issue of the ban and that despite the uncertainty related to the exact location of the fault, the local government has managed to deter development in this area. For example, during the "1946 to 1974 period", 0.38% of development in the study area took place inside the area subject to the construction ban, whereas during the "1992 to 1998" period the figure decreased to 0.03%. In other words, construction inside this area relative to the study area was reduced by a factor of approximately 10.

8.3.2 Vulnerability Assessment and Elements at Risk

Buildings

Table 8.6 contains an extraction of the relevant damage data developed by Sauter and Shah (1978). The increase in damage resulting from ground shaking levels is visible in this table. It highlights differences in damage between buildings without any form of seismic resistant design (types 1 and 2), those with deficient seismic design (types 3 to 5) and those properly designed (types 6 to 10). The increase in damage between MMI VII and MMI VIII for buildings without any form of seismic design ranges between 28% and 34% (an average factor of 2.38x), for those buildings with deficient design it ranges between 12% and 20% (an average factor of 2.96x) and for those with appropriate designs it ranges between 4% and 12% (an average factor of 3.96x). The implications of selecting one structural type over another are clearly visible in this table. For example, the difference in damage between adobe (mud-brick) buildings and reinforced masonry with seismic design for MMI VIII is an astonishing factor of 10.

Nowadays only wooden frames and buildings with seismic design (types 6 to 10) can be constructed. It is important to note the factor of 2.8 in the damage of the weakest type of building (reinforced concrete frames) in relation to that of the strongest type (reinforced masonry with seismic resistant design). This is highly relevant to urban planners and policy-makers as it would suggest that a mechanism to guarantee lower property losses is simply to encourage some types of seismically resistant designed buildings over others. This can be achieved by means of a combination of awareness campaigns within the engineering community and the general public, and tax incentives such as the application of different construction permit rates or annual property tax depending on the type of building type used.

Building Types	**Percentage of Damage**		Difference
	MMI VII	MMI VIII	
1. Adobe	22	50	2.27x
2. Un-reinforced masonry	16	40	2.50x
3. Reinforced concrete frames lacking seismic design	13	33	2.50x
4. Steel frames lacking seismic design	6	18	3.00x
5. Reinforced masonry lacking seismic design	5	17	3.40x
6. Reinforced concrete frames with seismic design	4	14	3.50x
7. Shear walls with seismic design	3	7	2.33x
8. Steel frames with seismic design	2	7	3.50x
9. Wooden frames	3	8	2.60x
10. Reinforced masonry with seismic design	1	5	5.00x

Table 8.6: Implications of Ground Shaking Intensity on Building Damage

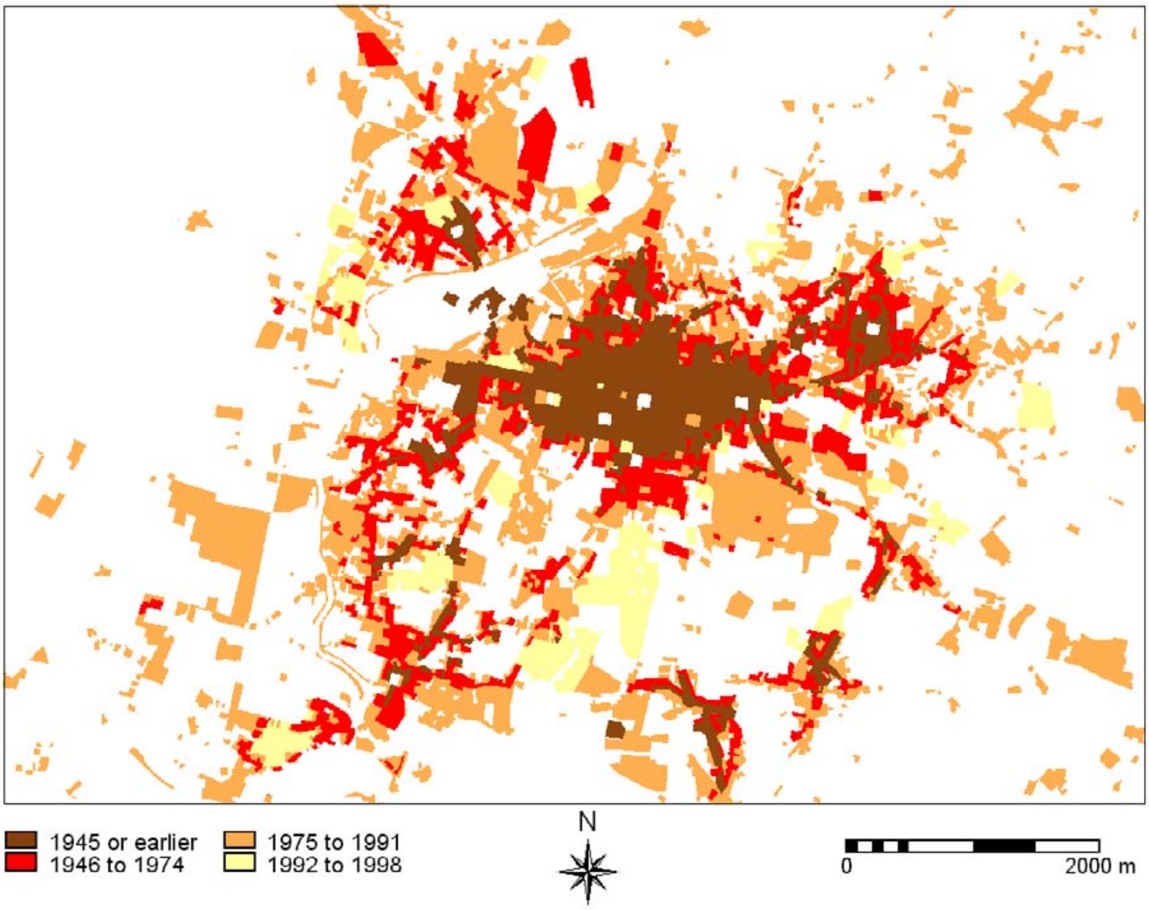


Figure 8.7: Urban Growth

These figures also indicate that adobe (mud-brick), un-reinforced masonry and reinforced concrete without proper seismic resistant design should be a major concern. During fieldwork, for example, one adobe (mud-brick) building used as a pub/disco was identified only a few hundred metres from the town hall. These types of structures are incompatible with such a land-use due to the high population concentrations and therefore the high casualties that could occur. There are a considerable number of these buildings in Cartago and unfortunately the local government lacks any form of inventory containing the location and present land-use of these structures. The digital cadastral database that is in the process of being set up is useless for this purpose as it does not contain data on building type. In the case of the pub/disco, it would record the land-use simply as "commercial". In the study area, since there has been a progressive improvement in buildings' response to earthquakes, a map of urban growth (see Figure 8.7) is particularly useful in identifying those areas where the older (and therefore weaker) buildings are located. This would make it possible to concentrate search efforts on a reduced area rather than wasting time searching in areas where such structures do not exist. In Cartago, the search for mud-brick and un-reinforced masonry buildings should therefore be restricted to an area equivalent to 15.98% of the urban land, the reason being that these types of buildings were not built after 1910, when the earthquake losses suffered caused a sudden shift towards wooden frame construction. Unfortunately, as Table 8.7 also illustrates, presently 32% of urban land is located on MMI VII and 68% on MMI VIII. The percentage of older buildings on MMI VIII land is unfortunately six points higher than the average.

Development Period	**Area in Hectares**	**% of Urbanized Area**	**% of Land on MMI VII**	**% of Land on MMI VIII**
Before 1945	258.32	15.98	26	74
1946 to 1974	341.14	21.11	38	62
1975 to 1991	859.77	53.19	32	68
1992 to 1998	157.03	9.72	23	77
Total urban	**1626.16**	**-**	**32**	**68**

Table 8.7: Urban Growth
(source: 1:10,000 IGN Series 1991 and aerial photographs of various years)

Despite the urban growth map being a valuable source of information for delimiting the perimeter where older structures are located, new building types also exist within the "before 1945" period. This is because some structures have been demolished and replaced by new ones constructed using state-of-the-art building materials and techniques. In Cartago this phenomenon is particularly visible as the demolition of buildings following the 1910 earthquake left many vacant pockets. Moreover, demolishing old buildings in Cartago has always been relatively easy as the National Heritage Law only protects about 10 structures. Table 8.8 highlights the mix of building types that exists within the various development periods identified, based on ground observations. For practical reasons, the development periods were defined based on available aerial photographs.

Building Type	Development Period			
	> 1945	1946 - 1974	1975 - 1998	1992 - 1998
1. Adobe walls	30.0	0.0	0.0	0.0
2. Un-reinforced masonry	33.0	0.0	0.0	0.0
3. Reinforced concrete frame lacking seismic design	0.0	20.0	3.0	0.0
4. Steel frames lacking seismic design	3.0	2.0	2.0	0.0
5. Reinforced masonry lacking seismic design	0.0	33.0	40.0	0.0
6. Reinforced concrete with seismic design	5.0	20.0	10.0	15.0
7. Shear walls with seismic design	4.0	0.0	3.0	5.0
8. Wooden frames	20.0	15.0	5.0	0.0
9. Steel frames with seismic design	0.0	0.0	2.0	5.0
10. Reinforced masonry with seismic design	5.0	10.0	35.0	75.0

Table 8.8: Percentage of Building Types According to Growth Periods
(source: ground observations)

The urban growth map is also relevant for making projections based on the analysis of past annual growth rates. Projections are useful in Cartago to identify the point in time when all vacant land of low hazard intensity levels will be consumed by development. This is important as the alternatives to consider then could be either to allow development on land with higher hazard intensity levels or to promote densification of existing urban areas.

Population

Census information provided the necessary inputs for generating a population density map for the night scenario. For the generation of the day population density map, a questionnaire was designed with the objective of establishing mobility patterns. Table 8.9 presents the results of the survey. However, regional centres have to be assessed separately in cases where the population they host comes from outside the area of study. In Cartago, the only “regional centre” worth considering for the production of a daytime population density map is the Instituto Tecnólogico de Costa Rica (ITEC). This institution is the only state-owned technological higher education entity in the country and it has a population of 7,500 students. Figure 8.8. illustrates the difference in population densities (expressed as population per ha) per census tracts and Table 8.9 provides a summary of the main findings (for an insight into the spatial modelling of the daytime population densities, refer to Chapter Five). The maps clearly illustrate that the population is more evenly distributed during the night than during the day when there is a tendency towards a concentration of population in the inner city.

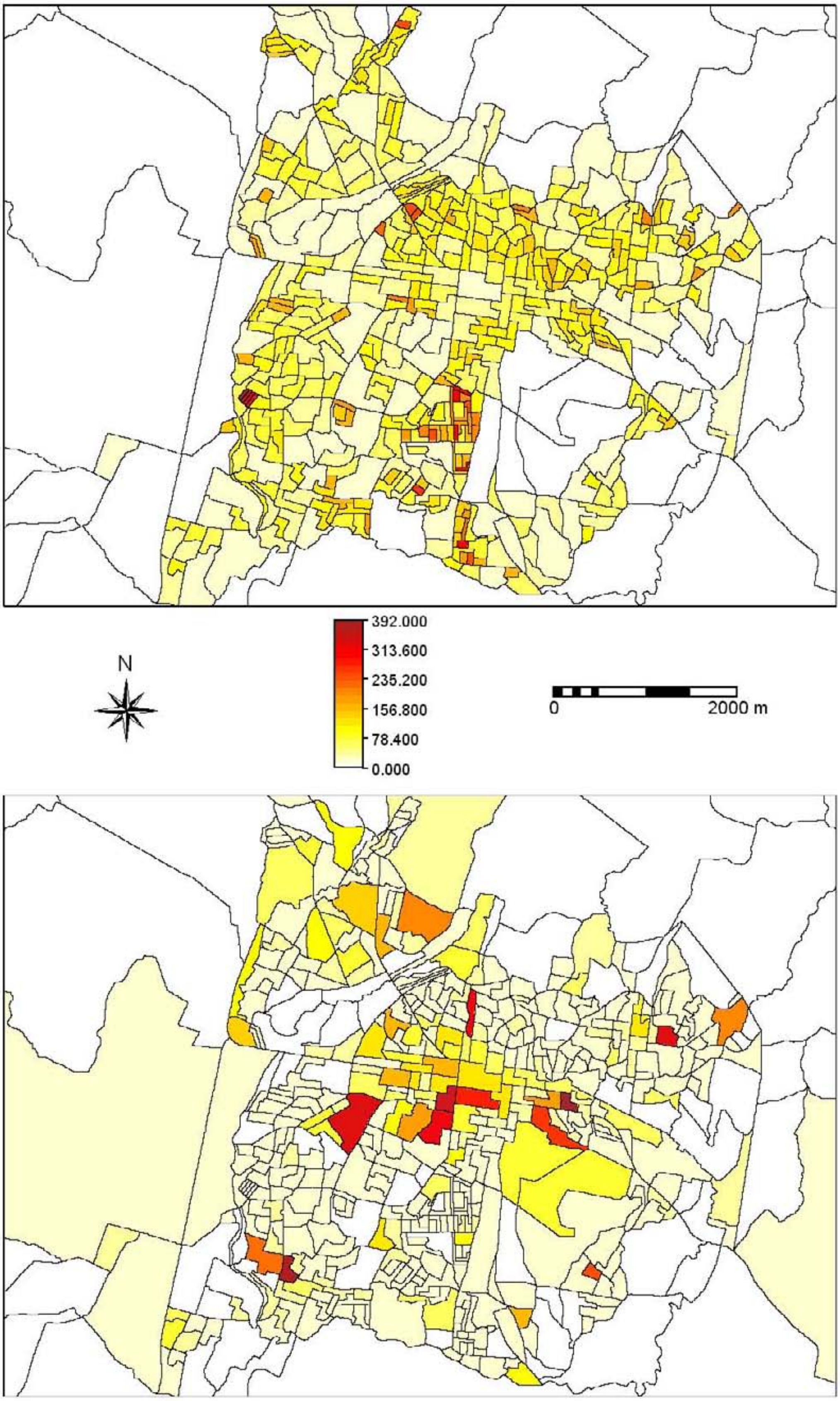


Figure 8.8: Population Density (Night Scenario (top) and Day Scenario (bottom)
(values expressed as persons per ha)

Age Groups	Percentage	Night Population	Day Population		
			Residential	Educational	Others[5]
0-4	9.88	12368	9269	3090	0
5-9	10.79	13507	0	13497	0
10-14	11.26	14096	0	14085	0
15-19	10.29	12882	644	10297	1931
20-24	9.00	11267	2252	2252	6755
25-29	7.76	9714	1456	679	7571
30-64	35.42	44341	10633	886	32786
above 65	5.60	7010	5604	0	1401
Total		**125085**	**29857**	**44785**	**50443**

Table 8.9: Distribution of Population during the Daytime

	Day Scenario		Night Scenario	
	Per Ha	Per Census Tract	Per Ha	Per Census Tract
Minimum	0.00	0.00	0.00	0.00
Maximum	391.04	8009.40	390.19	391.06
Average	35.79	269.35	81.12	224.05

Table 8.10: Population Densities for the Night and Day Scenarios

Table 8.10 highlights the large differences in total population per census tract. For example, the most extreme case relates to a census tract that during the day has 20 times more population than the census tract with the highest night population.

8.3.3. Risk Assessment

Table 8.11 illustrates the damage expected for each building type expressed both as area and as percentage. The percentage can be understood as either the percentage of the structure that will suffer total damage or the percentage of damage expected on each building of that structure type. Adobe (mud-brick) and un-reinforced masonry buildings are expected to suffer very high damage since 100% of these buildings are located on MMI VIII soil. Reinforced concrete frames lacking seismic design should also be of concern as the expected damage to this building type is high.

The figures presented in this table provide a general impression and they are meaningful from the point of view of developing details for zonation mapping (this is further developed in the following chapter). This data, however, is not suitable for assessing the rescue, relief or reconstruction implications or strategies as these require an insight into the area affected per damage severity level.

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[5] Includes institutional, industrial and commercial

Building Type	**Total Area** (in Ha)	**Damaged Area** (in Ha)	**Average Damage** (in %)
Adobe walls	77.50	38.75	50.00
Un-reinforced masonry	85.25	34.10	40.00
Reinforced concrete frame lacking seismic design	94.02	30.28	32.21
Steel frames lacking seismic design	31.77	5.60	0.00
Reinforced masonry lacking seismic design	456.48	75.27	16.49
Reinforced concrete with seismic design	190.68	26.05	13.66
Shear walls with seismic design	43.98	3.03	0.00
Wooden frames	145.82	10.03	6.88
Steel frames with seismic design	25.05	0.56	0.00
Reinforced masonry with seismic design	465.72	22.63	4.86
Total	1616.27	246.30	15.24

Table 8.11: Building Damage by Building Type

Table 8:12 illustrates the area affected per damage severity level. The severity levels used were those developed by the Applied Technology Council. As this table demonstrates, according to the damage figures by Sauter and Shah (1978), at the level of shaking intensity present in the study area some degree of damage is expected to all types of buildings. Approximately 44% of the buildings will suffer only slight damage while just 16% are expected to suffer heavy damage. These figures are highly relevant as they give an insight into the alternatives from a reconstruction point of view. This data is also highly valuable to relief workers as it can be used along with population density figures to estimate the number of people in need of temporary short-term and long-term accommodation.

Category of Damage	**Percentage of Damage**	**Area** (in Ha)	**Number of Buildings**	**Percentage of Buildings**
Slight	0.01 – 0.99	0.00	0	0.00
Light	1.00 – 9.99	703.94	17600	43.56
Moderate	10.00 – 29.99	658.06	16450	40.72
Heavy	30.00 – 59.99	254.04	6350	15.72
Major	60.00 – 99.99	0.00	0	0.00
Destroyed	100.00	0.00	0	0.00
Total		1616.04	40400	

Table 8.12: Building Damage per Severity Level

This building risk is the input for the generation of the population risk figures along with population vulnerability ratios. Since Costa Rica has not developed population vulnerability ratios, the ones developed by Emergency Preparedness Canada (1997) were used in the case study. These vulnerability ratios are given per damage severity level and for three different types of injury: minor injury, major injury and death. This breakdown into three classes is convenient from the point of view of planning for rescue and planning for health service delivery.

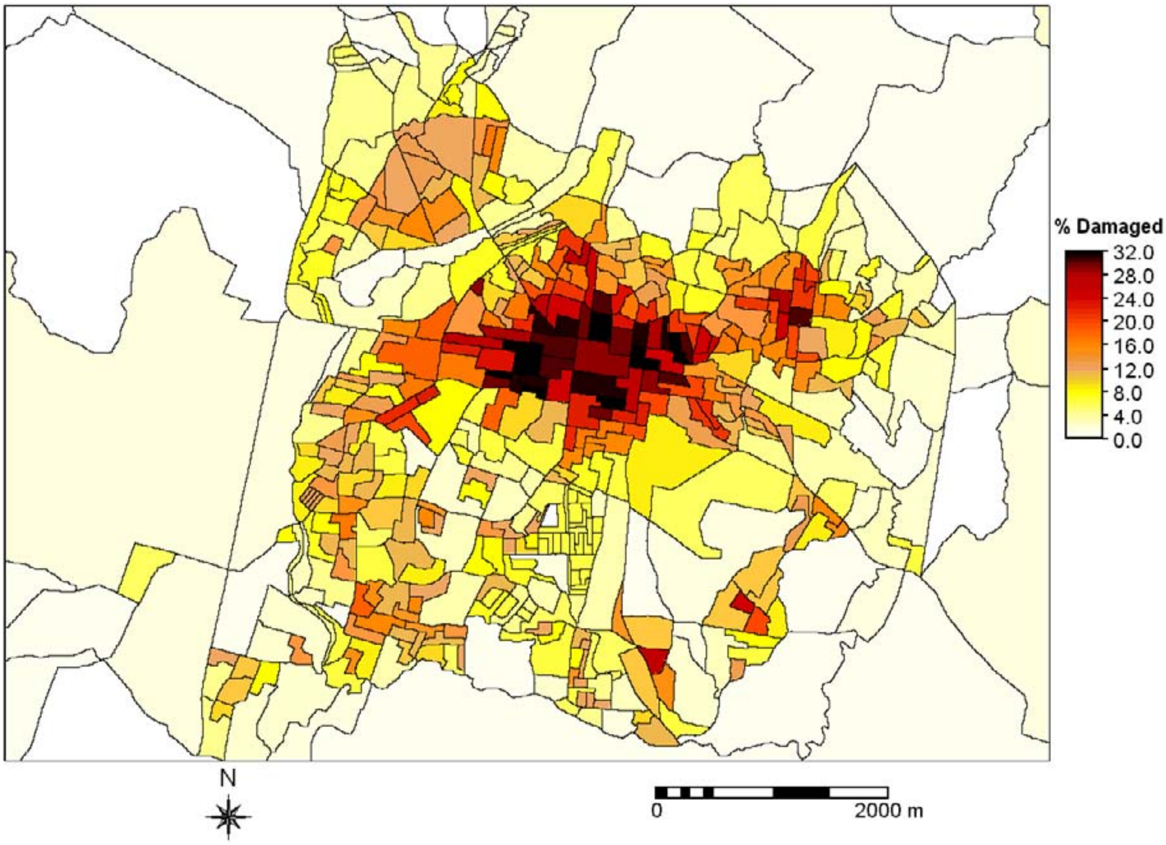

Figure 8.9: Building Damage Ratios

The summary of injuries for the day and night scenarios is presented in Table 8.13, while a comparison of minor injury density between the day and night scenarios is presented in Figure 8.10. The difference in the injuries between these two scenarios is a factor of 1.29x. Figure 8.10 clearly illustrates that there are higher concentrations of injuries in the inner city during the day compared with the night.

These injury figures should be compared with those related to the capacity of the medical infrastructure network to determine whether the local facilities are able to cope with the degree of casualties expected or whether there is a need to network with other hospitals and clinics located in nearby urban areas. In Cartago, the Max Peralta hospital has a total number of 261 beds and a morgue with capacity for six bodies. It is therefore clear that the hospital would be overwhelmed and networking with the nearest hospitals (Calderón Guardia in San José and Turrialba hospital) would be necessary. The Calderón Guardia hospital has a capacity of 622 beds while the Turrialba hospital has a capacity of 261 beds. If bridges are damaged and water levels are high in the river basins, the transfer of patients is only possible by helicopter since Cartago has no airport – thus the importance of infrastructure risk assessment becomes obvious. The same type of assessment must be performed for other types of emergency organisations, such as the fire brigade and the paramedics.

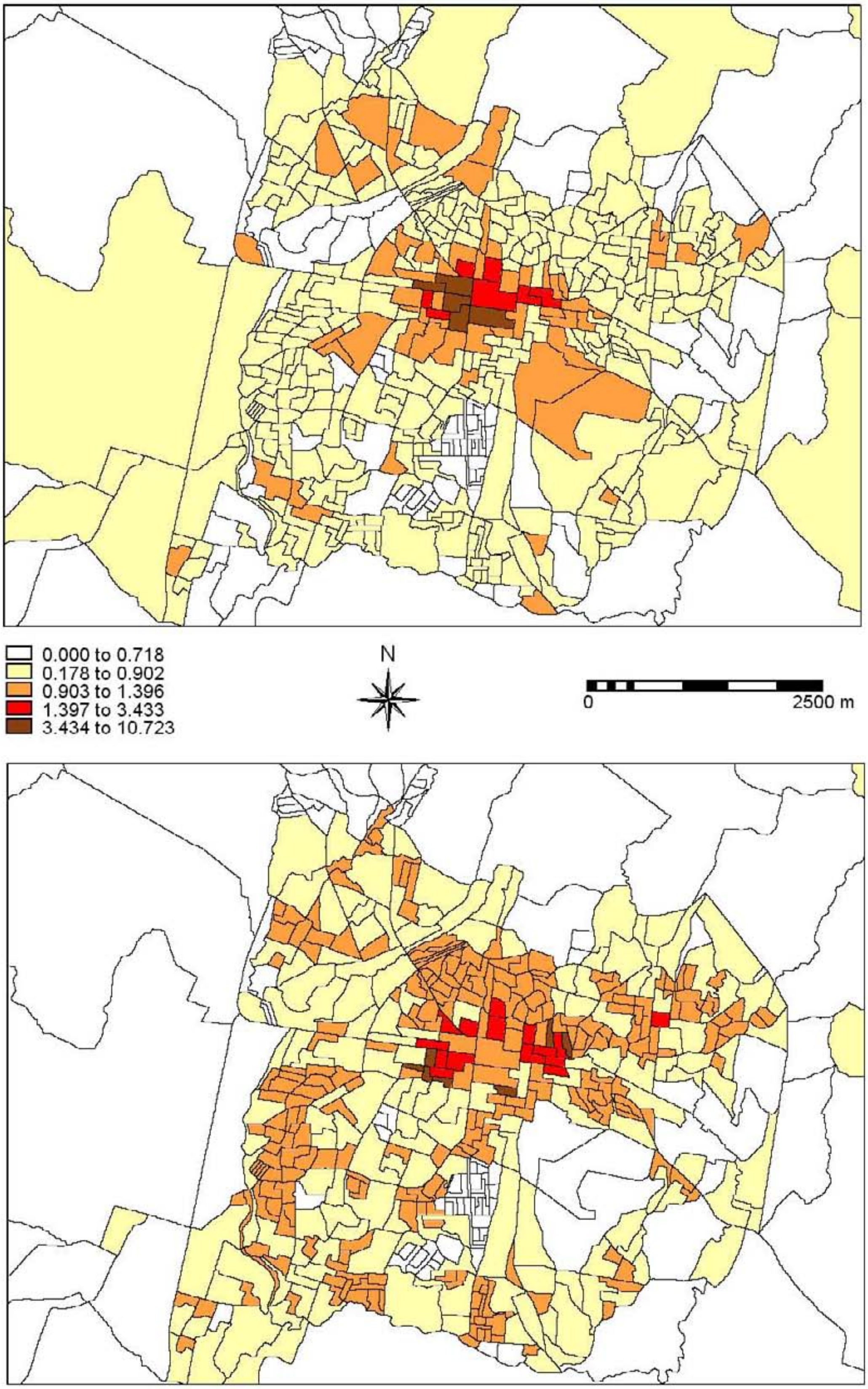

Figure 8.10: Minor Injuries (expressed as injuries per ha)
Night Scenario (top) and Day Scenario (bottom)

Injury Level	Day Scenario	Night Scenario
Minor injuries	631	489
Major injuries	84	66
Deaths	21	16
Total	736	571

Table 8.13: Number of Injuries per Injury Level and Type of Scenario

8.4 COST-BENEFIT ANALYSIS OF MITIGATION STRATEGIES

This section illustrates how risk assessment is incorporated into the urban planning process from the point of view of both prevention and reduction. To guide future development, the modification of tax rates by means of hazard intensity and vulnerability is discussed. Regarding redevelopment in existing built-up areas, two reduction scenarios are used to illustrate how risk assessment is used as an input in a cost-benefit analysis, as well as how the results of this analysis are likely to be interpreted by decision-makers.

8.4.1 Development Scenario

When considering land available for future expansion, 52.24% of the vacant land that is not affected by a natural hazard-related construction ban falls under MMI VII, while the remaining 47.76% falls under MMI VIII. Careful planning is therefore necessary as ideally the vacant land under MMI VII should have priority over the rest of the land. The issue of construction types is also important – Table 8.6 highlights the difference in damage rates between seismically designed construction types. The important decision for the Municipality of Cartago is whether to ban or encourage construction in a given area, or whether to combine both approaches. From the natural hazard point of view, the current legal framework bans construction on slopes greater than 25%, along active faults and along rivers. The remaining bans are either related to technological hazards, aesthetics or inadequate light, ventilation and circulation.

Since there are only two levels of ground shaking intensity in the study area, banning construction on MMI VIII land would be difficult, especially without an official large-scale micro-zonation map to back this decision. Achieving the development of certain building types in particular locations requires an aggressive approach by the local government. To be successful, both the developer and the future owner should benefit from a financial incentive scheme. An alternative in Cartago is to use the damage ratios developed by Sauter and Shah (1978) to establish modifiers on the value of the construction permit and annual property tax on new buildings. The application of different construction permit rates depending on location and construction type probably has little effect on individuals who already own a plot and want to erect an individual building. On the other hand, it would have a definite effect on commercial developers as it would constitute a strong weight factor with obvious implications for profit margins. Conversely, future building owners who are shopping around normally do not have any great understanding of construction types, but they would be encouraged to purchase those constructions bearing the lowest annual tax. The developer would therefore be forced to respond to market preferences.

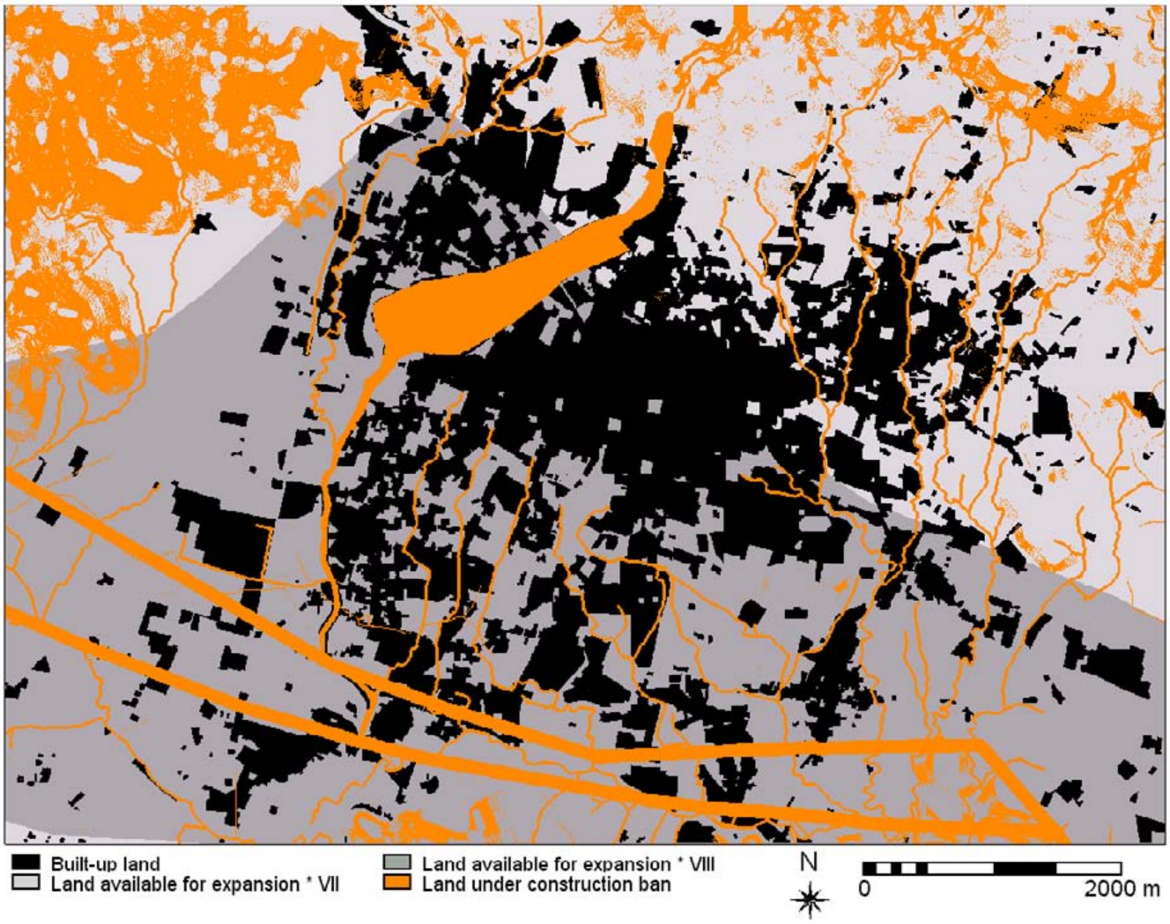

Figure 8.11: Zonation for Development

	VII		VIII	
Building Types	**Damage Ratio**	**Modifier**	**Damage Ratio**	**Modifier**
Rc frames-sd6	0.04	2.50	0.14	7.50
Shear walls-sd7	0.03	2.00	0.07	4.00
Steel frames-sd9	0.02	1.50	0.07	4.00
Wooden frames8	0.03	2.00	0.08	4.50
Rm-sd10	0.01	1.00	0.05	3.00

Table 8.14: Proposed Modifiers to the Construction Permit Rates

Table 8.14 illustrates the proposal for establishing different construction permit rates depending on construction type and intensity of ground shaking. The construction type with the lowest damage ratio has been selected as the base value. The implementation of this method would require the updating of the construction type list because important building types such as pre-cast construction panels are now a very popular choice but were not included by Sauter and Shah – probably as they were not widely used during the mid-seventies. In the case of buildings with mixed structural types, the rates would have to be applied to the dominating structural type. It is not expected that this would add to the administration costs of the local government as the responsible engineer and architect already carry out the assessment of the structural type at the time of the application for building permits.

8.4.2 Redevelopment Scenario

At first glance, it would appear that re-strengthening adobe (mud-brick buildings) should be a priority in Cartago. Unfortunately, due to the lack of cohesiveness of the type of mud-brick used in Cartago (consisting of mud, straw, broken pieces of clay tile and even egg white!), the material does not bear any form of re-strengthening. The only option would be to attach a mesh to both sides of the wall and cover it with plaster. This is a method that is already being used; the Peruvian city of Trujillo is an example. Although this hardly decreases the damage to the building, it does provide the dwellers with a few extra seconds for evacuation. This alternative is therefore valuable from the point of view of population risk rather than both building and population risk.

Two reduction scenarios have been developed based on those building types that have the highest damage ratios (refer to Table 8.6) per intensity level. It must be noted that since detailed hazard zonation maps do not exist for all the hazard scenarios, Sauter's flat peak ground acceleration (PGA) values (refer to Figure 7.22) are used in this section. In other words, from this point onwards it will be assumed that for all probability scenarios, the study area falls under one motion intensity.

- Scenario A contemplates the replacement of all adobe structures and un-reinforced masonry buildings with reinforced masonry structures, as well as the steel bracing of all reinforced concrete frames without seismic design. This reduction scenario therefore covers an area of 256 ha, which is equivalent to 15.8% of the urban area.
- Scenario B contemplates only the steel bracing of all reinforced concrete frames without seismic design. This reduction scenario involves re-strengthening buildings, covering an area of 94 ha, roughly 5% of the urban area.

Return Period	Millions of US$		
	Unmodified	Scenario A	Scenario B
1	0.95	0.00	0.95
11	109.30	13.77	41.32
29	272.33	164.65	246.95
64	516.68	338.97	477.19
137	761.02	513.30	707.43
227	990.88	686.11	923.89
363	1220.74	858.92	1140.35
619	1450.60	1031.73	1356.81
1007	1680.46	1204.55	1573.28

Table 8.15: Total Building Losses per Mitigation Scenario

The total figures presented in Table 8.15 point out the maximum possible losses that could take place in Cartago. Despite a return period of 1,007 years, authorities should be aware that at any point in time, the city could be confronted with an event that has the potential to destroy 506 ha of buildings, which represents approximately US$ 1.7 billion-worth of property. The losses from this event would represent 34.70% of the building property of the city of Cartago. Consequently, this would constitute a major catastrophe which, given the size of emergency services in Cartago (for a basic description of the health infrastructure of Cartago, refer to Section 8.3.3), would involve the pooling of resources over a wider area. In this sense, this catastrophic risk scenario highlights the regional dimension of disaster management.

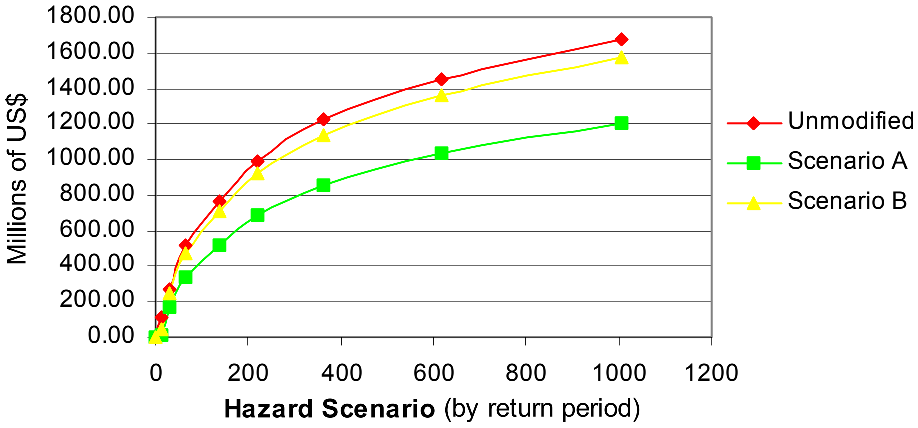

Figure 8.12: Total Building Losses

On the other hand, annual figures are crucial as a standardisation of risk scenarios allows planners to put things into perspective. In Cartago, due to the variety of natural and technological hazards, the conversion of losses into yearly values is a key input for strategic disaster management. Figure 8.13 clearly illustrates that, in terms of annual building losses, high probability events cause higher losses compared with medium and low probability events. An important finding of this analysis is that, contrary to popular belief, the 137-year return-period earthquake thought to have an epicentre a few kilometres from the centre of town is not the most damaging one. The most damaging event is the 11-year return-period event, which has a PGA value of 0.12 g, closely followed by a 29-year return-period phenomenon with a mere 0.08 g ground motion value.

As can be observed from Table 8.16, the reductions achieved by implementing the two mitigation scenarios under consideration are not constant throughout the hazard scenarios (return periods) due to the response of buildings to ground motion. On average, mitigation scenario A yields a reduction factor of 0.46 (standard deviation of 0.28) while scenario B provides a 0.12 reduction factor (standard deviation of 0.19).

Return Period	**Millions of US $**			**Reduction Factor** (1: highest, 0: lowest)	
	Unmodified	**Scenario A**	**Scenario B**	**Scenario A**	**Scenario B**
1	0.95	0.00	0.95	1.00	0.00
11	9.94	1.25	3.76	0.87	0.62
29	9.39	5.68	8.52	0.40	0.09
64	8.07	5.30	7.46	0.34	0.08
137	5.55	3.75	5.16	0.33	0.07
227	4.46	3.09	4.16	0.31	0.07
363	3.36	2.37	3.14	0.30	0.07
617	2.34	1.67	2.19	0.29	0.06
1007	1.67	1.20	1.56	0.28	0.06

Table 8.16: Annual Building Losses and Mitigation Reduction Factor

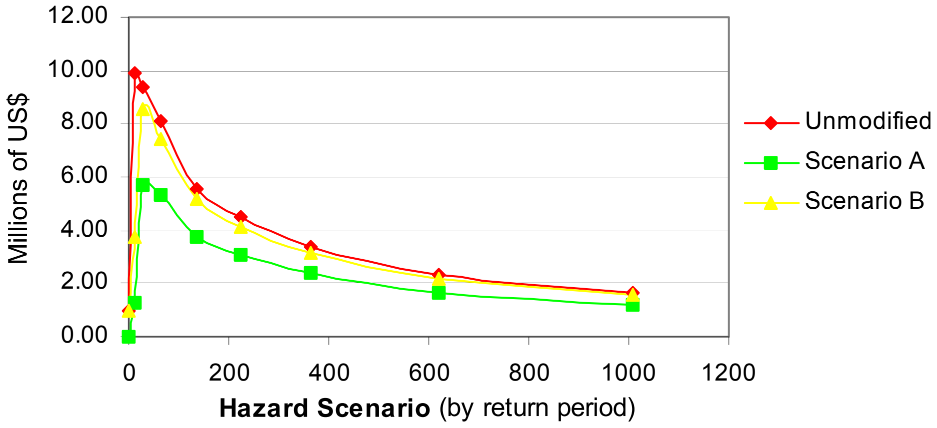

Figure 8.13: Annual Building Losses

As Figure 8.14 illustrates, despite a return period of 1,007 years, at any point in time, the city could be confronted with an event that has the potential of causing approximately 116 deaths, approximately 463 people with major injuries and 3,424 with minor injuries (0.8%, 3.1% and 2.28% of the population respectively). Appendix V highlights the variation in the number of casualties depending on the time of the day for the various probability scenarios.

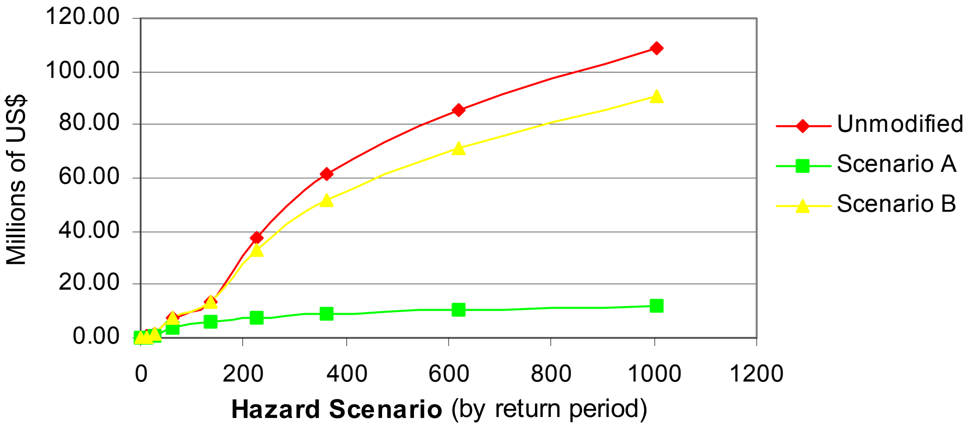

Figure 8.14: Total Casualty Losses

For the estimation of human capital losses, the following figures were used (refer to total figures in Table 8.17 and detailed annual figures in Appendix VI):

- Average population age of 27 (Instituto Nacional de Estadística y Censos 2001)
- Retirement at 65
- Life expectancy of 77 (Instituto Nacional de Estadística y Censos 2001)
- Monthly income of US$ 442 (Ministerio de Planificación y Política Económica 2002)
- Pension of 80% of last salary
- Annual inflation rate of 3%

		Inflation Rate						
		0 %	**1%**	**2%**	**3%**	**4%**	**5%**	**6%**
Earnings	Age 27 - 65	235,443	286,228	351,578	436,078	545,800	688,792	875,718
Pension	Age 66 - 77	57,955	90,292	140,221	217,074	335,003	515,417	790,594
Total		293,398	376,520	491,800	653,152	880,803	1,204,208	1,666,312

Table 8.17: Calculation of Lost Human Capital (values in US$)

For the calculation of losses attributed to major casualties, it was assumed that one in 10 of this class was permanently disabled while the rest had a period of one year of hospitalisation and recovery. For minor injuries, a period of two weeks of work leave was assumed.

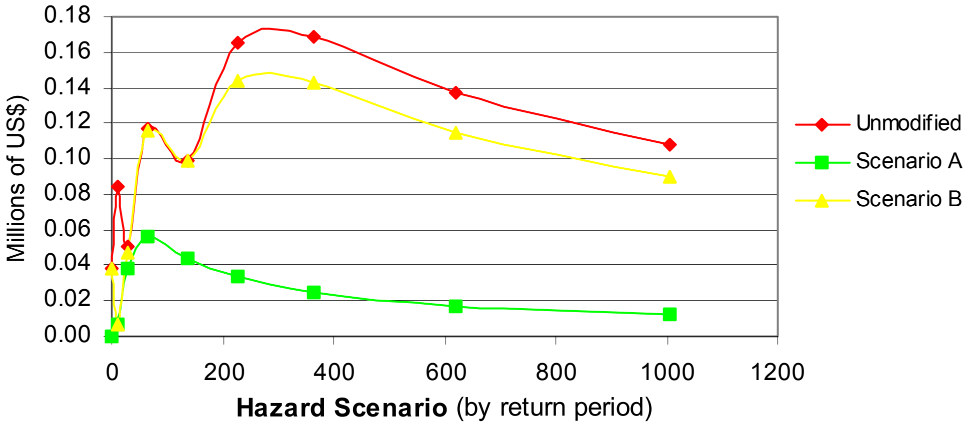

Figure 8.15: Annual Casualty Losses

Interestingly, as Figure 8.15 and Table 8.18 illustrate, the analysis of annual casualty losses yields a different result to that of annual building losses. Low probability events cause higher losses than high probability events do. Once again, the 137-year return-period earthquake is not the most damaging one. The most damaging is the 363-year return-period event, which has a PGA value of 0.28 g, closely followed by a 227-year return-period phenomenon with 0.24 g ground motion value. On average, mitigation scenario A yields a reduction factor of 0.74 (standard deviation of 0.25) while scenario B provides a 0.18 reduction factor (standard deviation of 0.28).

Return period	**Millions of US$**			**Reduction Factor**	
	Unmodified	**Scenario A**	**Scenario B**	**Scenario A**	**Scenario B**
1	0.04	0.00	0.04	1.00	0.00
11	0.08	0.01	0.01	0.91	0.91
29	0.05	0.04	0.05	0.24	0.08
64	0.12	0.06	0.12	0.52	0.01
137	0.10	0.04	0.10	0.55	0.00
227	0.16	0.03	0.14	0.80	0.12
363	0.17	0.02	0.14	0.85	0.15
619	0.14	0.02	0.12	0.88	0.16
1007	0.11	0.01	0.09	0.89	0.17

Table 8.18: Annual Population Losses and Mitigation Reduction Factor

For the calculation of the benefits of both mitigation scenarios, the following assumptions were made:

- Both adobe and un-reinforced buildings are demolished and rebuilt. Although the demolition and clearance of rubble implies a cost, this is balanced by the re-use of materials such as timber and roofing. Therefore, the cost will be calculated at 100% of the replacement cost.

- It is assumed that the cost of bracing reinforced concrete frames without seismic design is approximately 10% of the replacement cost of the building.

The mitigation costs of scenario A are US$ 521.65 million while for scenario B the figure is only US$ 28.49 million.

	Annual Benefit					
Return Period	**Population**		**Buildings**		**Total Benefits**	
	Scenario A	**Scenario B**	**Scenario A**	**Scenario B**	**Benefits A**	**Benefits B**
1	0.04	0.00	0.95	0.95	0.99	0.00
11	0.09	0.09	8.68	8.68	8.77	6.27
29	0.02	0.01	3.71	3.71	3.73	0.89
64	0.06	0.01	2.78	2.78	2.84	0.63
137	0.06	0.00	1.81	1.81	1.87	0.39
227	0.12	0.02	1.37	1.37	1.49	0.32
363	0.14	0.03	1.00	1.00	1.14	0.25
617	0.13	0.03	0.68	0.68	0.81	0.18
1007	0.10	0.02	0.47	0.47	0.57	0.13
Total	0.76	0.21	21.45	21.45	22.21	9.05

Table 8.19: Benefits of Mitigation Scenarios

Table 8.19 demonstrates that the building losses outweigh human capital by a factor of about 16. This is an important finding as it has implications in terms of policy-making. For example, if there is a clear policy to give priority to life, a weight should be applied to human capital as part of the cost-benefit analysis of mitigation scenarios.

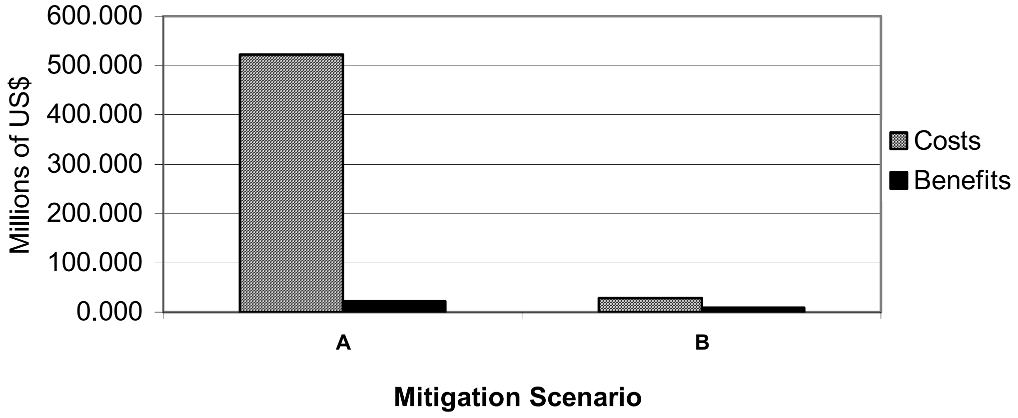

Figure 8.16: Cost-Benefit Analysis per Mitigation Strategy

This analysis also illustrates how at first glance mitigation scenario A appears the most attractive. However, from the analysis of the cost and benefit figures, it could be argued that scenario B is more efficient (refer to Figure 8.16) as there is a 23.5 to 1 cost-benefit factor in the case of scenario A while the factor is only 3.15 in the case of scenario B. A way of interpreting these results is to view scenario A as being long-term, as only after 23.5 years is a cost-benefit of 1:1 reached. Conversely, scenario B constitutes a short-term scenario as it achieves a cost-benefit of 1:1 in 3.15 years.

The cost-benefit values above are partial figures, as important factors were not taken into account due to lack of damage data (loss of building contents, interrupted business, costs of temporary accommodation for displaced persons, costs of the rescue and the relief itself, to name just the most important).

8.5 CONCLUSIONS

It was concluded that a detailed and updated land-use map, a map of urban growth, damage curves and a map of population densities are the most important “urban” datasets for urban disaster management. It also was concluded that Remote Sensing is an important tool not only for generating datasets such as the map of urban growth but also for cutting down on the extent of ground data collection. The results of the population risk assessment illustrated the effect that the time of the day has on the spatial distribution of casualties. Finally, it was concluded that unless mitigation alternatives are analysed on a cost-benefit analysis and are standardised based on probability data, there is the possibility that a wrong alternative will be adopted.

Chapter Nine: CONCLUSIONS AND RECOMMENDATIONS

This chapter draws conclusions based on the previous eight chapters and presents recommendations for further research. The conclusions relate to methodology development for urban disaster management in general, and more specifically to data capture of elements at risk. An action plan related to geo-information for disaster management, and some guidelines for disaster management in Cartago are also presented.

9.1 CONCLUSIONS

9.1.1 Data Capture Methodology

The approach adopted is pragmatic, in the sense that, given the human and financial constraints typical of developing countries, it involves an initial classification of buildings based on their relevance for emergency and relief operations and it proposes different data capture methods accordingly. Those areas that do not include relevant buildings undergo a second classification designed to reduce the extent of the data capture phase. The classification of buildings (regular, essential second priority, essential first priority) was designed based on three types of data capture methods (rapid visual sidewalk screening, extensive screening and analytical modelling). It is thought that this data capture would be easy to coordinate and implement given that three very distinct levels of expertise in structural response exist within the professional community: a) architects and construction technologists, b) civil engineers and c) structural engineers. This classification also takes into account the levels of human resources availability, as structural engineers tend to be very scarce.

The first main conclusion regarding this approach is that it is dependent upon the availability of up-to-date large-scale land-use maps and aerial photographs. The land-use maps are necessary to identify emergency-related buildings, while the aerial photographs are needed to delineate homogeneous areas.

The mission planning phase proved straightforward provided that a centre road line map was available, but for optimal results the direction of traffic circulation should also be considered. One could argue, however, that if such a detailed network map is unavailable, the costs and time involved in generating one would be prohibitive if it was for the sole purpose of preparing for image capture.

For the purpose of urban planning it was concluded that, despite the great advances in remote sensing, building risk cannot be assessed based on remotely sensed images alone and that ground observations are necessary to complement them. However, if building types and construction practices are consistent within distinct development periods, remotely sensed images can be used to conduct a risk assessment at a metropolitan or regional level as long as results are aggregated to the district level.

It would be stating the obvious to highlight the usefulness of GIS for the input, management, manipulation, analysis and visualisation of spatially referenced data as there are plenty of examples that have already demonstrated this. What is important at this point is to draw attention to two aspects of GIS, one relating to scenario development and the other to the emerging mobile technologies.

In the case study, the initial stages of data manipulation proved very time-consuming. However, the greatest strength of GIS proved to be its ability to handle the “what if” type of scenarios. Converting the original forecast into a scenario that, for example, illustrated “what if all buildings with reinforced concrete frames without proper seismic design are braced?” was carried out in very little time.

Mobile GIS enables both the collection of data as well as its processing to be carried out directly in the field. During fieldwork, an off-the-shelf and low-cost alternative for collecting data on the characteristics of building façades was tested with very successful results. A budget GPS unit was used in combination with a digital video camera and a laptop computer. The coupling of these devices proved possible and straightforward and it was concluded that these technologies have great potential in pre-disaster data collection, although it is probably during the post-disaster damage reconnaissance phase that they would be of highest value. Since digital video cameras are widely available and are relatively inexpensive, it is thought that this method is a viable option from a financial point of view, especially in medium and small municipalities in developing countries. This method proved very flexible and it can be used for many applications, even in non-urban contexts.

9.1.2 Data Production and Integration

Hazard Zonations

In Costa Rica, a micro-zonation of the Great Metropolitan Area (GAM) is urgently needed as approximately 54% of the population lives and works in this small area of approximately 1,775 km^2, which represents 3.5% of the area of the country. Moreover, it is expected that by the year 2025, the population of the GAM will increase to 75% of the total population. As discussed before, there is a seismic zonation of the GAM at scale 1:200,000. Unless hazard zonations are carried out at large scales, however, issues such as local site conditions cannot be incorporated, leading to inaccurate risk assessments and inadequate strategies in the field of planning of urban expansion. This therefore implies that detailed contour and soils mapping must be generated for the whole of this region. So far, contour mapping is available for the entire GAM area at 1:10,000 scale, and it would be ideal if soil maps were available at the same scale – however, a scale of 1:25,000 could be a reasonable compromise. Specific mention of hazard probability should be made as it was observed that several hazard zonations did not include details about the probability of the event within the map itself. Since risk assessment consists of a sequence of analyses carried out by different teams of scientists, the individual groups of scientists should make explicit mention of all basic components in order to smooth the process.

Institutions such as the Ministry of Natural Resources and the Environment (MINAE), the National Commission for the Prevention of and Response to Emergencies (CNE), the School of Geology of the University of Costa Rica (UCR) and the Central American School of Geology are key in the elaboration of these zonations. The university would play a leading role as undergraduate and postgraduate students could conduct part of the required mapping as part of their final assignment or thesis, provided that adequate supervision was given. Apart from local and regional government planning and management entities, the National Insurance Institute would benefit greatly from these maps. The establishment of a partnership between these institutions could make both the funding and the human and technical resources available for the elaboration of these maps.

An inconsistency between literature on the topographic effects on building damage and the Costa Rican Seismic Code of 1986 was identified. The literature indicates that a correlation exists between large topographic changes and damage to buildings, and that a ban on construction along all scarps should be enforced. While the code does impose a ban on construction within 50 m either side of active faults, it makes no mention of a similar ban affecting scarps. This is an issue that should be addressed by the National Federated Board of Architects and Engineers (CFIA), which was the author of the 1986 National Seismic Code, and the School of Geology of the University of Costa Rica (UCR). Such a ban would represent another important element to be incorporated in a development zonation.

Vulnerability Functions

The literature review identified the most important characteristics having an effect on building damage to be: structural type, building material, building configuration foundations, number of storeys and a benchmark related to the implementation of seismic codes and relevant regulations. Unfortunately, of these listed items, foundations present the greatest difficulty in the process of vulnerability assessment. As they are not visible, they cannot be incorporated in methodologies dealing with data capture by means of rapid sidewalk or extensive screening. In this sense, foundations may be regarded as the “weakest link” in this process and this explains why some professionals in the field of structural engineering view risk assessment with considerable scepticism. That said, risk assessments carried out in California and later verified based on the damage observed from the 1994 Northridge earthquake suggest that the omission of foundations in risk assessment methodologies did not lead to higher error. This phenomenon may be the result of particular foundations being used for particular building types. Consequently, so long as this is the case, the reliability of the forecast is not compromised.

Nowadays, since there is consensus regarding the effects of soil and topography on building damage, a wide range of foundation types can be associated with a particular building type. It can therefore be concluded that the assumption that all buildings of a given type will have a given foundation type will become less valid in the future, and hence this criterion should be incorporated in building vulnerability methodology. This implies not only the need for architects or engineers to specify the type of foundation during the construction permit application, but also the development of quantitative data that enables the modification of the "basic damage rate" for a building type according its foundation type.

A finding of the Cartago case study was that to a certain extent the plan and vertical configuration of buildings could be assessed through remotely sensed and ground images. However, the distribution of rigidity (refer to Appendix III) could not be assessed by either of these methods. Unfortunately, even if all three types of configuration criteria (plan, vertical and structural rigidity) could be assessed, there is still a lack of historical damage data, and therefore quantitative vulnerability functions need to be developed. Mobile GIS could be the technology to bridge this gap, as it would speed the process of post-disaster data collection and therefore enable the collection of more building attributes before the start of demolition work.

In Costa Rica, damage curves have been available since the 1970s. However, the following three improvements must be made:

- The incorporation of the number of storeys, since buildings of different heights shake at different frequencies
- The expansion of the list to include recently adopted structural types such as pre-cast concrete panels
- An indication regarding the judging of constructions which consist of mixed building types

Having said that, from the point of view of data collection and its interpretation, this list of building types should be as concise as possible.

Since the previous damage curves were developed for the National Insurance Institute (INS), it is thought that this organisation could expand its role by improving and periodically updating the damage curves.

Elements at Risk Database and Mapping

The case study highlighted both the strengths and weaknesses of the data available and the extent to which this data could be exploited for risk assessment. The establishment of baseline data is one of the most important and neglected functions of emergency information management in Cartago. Effective emergency decision-making requires data collected by damage reconnaissance teams to be compared with the baseline data representing the "normal" (pre-disaster) situation. Of the datasets used, the local government generated none. In the future, this situation will probably change as the local government will operate a digital cadastre and this will not only make it possible to generate a few information products but it will also encourage officials to generate other data layers. A more proactive role is required from the municipality, while a more supporting role is required from the national urban planning entity, which has until now largely monopolised urban plan making.

The case study illustrated the vast number of buildings involved in full surveys and the need for conducting stratifications to narrow down the extent of the ground surveys. The national government should therefore make the necessary budget allocations for the production of remotely sensed images, as these are the most useful products for stratification purposes. The National Geographic Institute (IGN) should not only have recent photographs available but it should also make efforts to avoid the discontinuation of the 1:10,000 series of land-use maps of the Great Metropolitan Area (GAM). These maps have so far only been produced in 1991 and despite the success of the series, it is thought to be heading for discontinuation due to its cost. If, however, there is a decision to discontinue the series from a cost-benefit point of view, an alternative would be to explore the expansion of the land-use classification of the cadastre. This institute should also engage in the coordinate transformation of not only the 1:10,000 series but also the 1:50,000 scale series, as due to the old projection used these maps do not match data collected using GPS. This issue is increasingly important as GPS is an increasingly important tool in the pre-disaster collection of data, but it will be widely used by disaster reconnaissance teams who require relatively accurate data to be generated as quickly as possible.

Municipal governments should make periodic recordings of building façades using digital video in a moving vehicle. This offers advantages not only from the point of view of disaster management but also from the point of view of tracking down illegal construction, advertisements and land-use changes. Consequently, digital video should be used as a tool in establishing fines and therefore in revenue collection – so long as this does not challenge the privacy laws. Moreover, digital video cameras are nowadays widely available and can be easily rented for short periods. Since this type of equipment would be infrequently used, and given the size of Costa Rica, the Institute for the Assistance and Stimulation of Municipalities (IFAM) is the ideal entity to run a loan system of digital video and GPS devices which would improve the ability of small local government departments to collect relevant data at given intervals.

One of the most important challenges relates to the municipal cadastre as a basic platform on which to build risk assessment. The case study demonstrated that whenever cadastral data is unavailable, it is necessary to make gross assumptions related to the area of construction. This is obviously undesirable from the point of view of the reliability of the data that is then used in the cost-benefit analysis of mitigation strategies. Basically three improvements are necessary if the cadastre is to be useful:

- The valuations contained in it should represent up-to-date replacement values and market values separately, rather than simply a nominal value that cannot be disaggregated. This requires an aggressive overhaul of the cadastre, and the increase in revenue resulting from up-to-date valuations could be used to fund the salaries of extra staff. At the moment, market values are only being established by real estate companies and they tend not to make this information public for obvious reasons. Replacement values can only be derived from the six-monthly estimates of construction costs issued by the Federated Board of Architects and Engineers (CFIA). At present, the classes of buildings used by the CFIA do not match the classification of damage functions developed by Sauter and Shah (1978). The issue of comprehensiveness and consistency in the building classifications used by the different groups that produce data usable for risk assessment has to be addressed.
- The classification of land-uses contained in the cadastre database is very restricted and it should therefore be extended, especially if detailed land-use maps do not exist.
- The number of storeys of buildings should be recorded. At present only the total area of the building (and the parcel) is recorded. Since different heights shake at different frequencies, without knowledge of height it is not possible to accurately calculate the damage for several earthquake scenarios. The land-use per storey is also important from the point of view of establishing population density scenarios throughout the day.

The case study has illustrated the variation in casualties depending on the time of day. It therefore highlights the need for models and data for accurately estimating the population density during the day (as census data is based on night-time occupancy). This underlines the importance of producing complementary censuses, for example the “business census”, which records characteristics of industrial and commercial establishments, such as the total number of employees.

Spatially referenced inventories of school facilities and health facilities are also important sources that can be used for producing the day population density scenario. In Costa Rica, a business census does not exist, although this data is available through other sources such as the tax office, either at national level (*Tributación Directa*) or at local government level itself. The difficulty in using data from the tax office, the local government or the ministries of health or education is that their data cannot be easily geo-coded.

In Cartago, as across the whole country, the Spanish colonial grid carries avenue and street numbers. After the use of the grid pattern was abandoned, however, new streets were given no names and presently, under a rather unique system, addresses are given in the form of distance from a widely known feature. Although this system seems to allow local people to find their way around, it makes it practically impossible to geo-code buildings or plots. To make matters even worse, there is no such thing as a post-code system. Unfortunately, this issue has been completely neglected by politicians as they consider an address and post-coding system to have little importance and minimal political leverage. However, to move forward in the application of GIS, not only for disaster management but for a variety of other purposes as well, the government must launch a programme that funds and empowers Correos de Costa Rica (the post entity) to develop a nationwide street address and post-coding system. Pressure is therefore needed from technocrats to highlight the wide-ranging applications of such a system, beyond the postal service.

On the other hand, the funding necessary to generate basic datasets such as the national population census and aerial survey photographs has to be ensured, as the availability of data generated at given intervals is important not only in risk assessment but also for monitoring mitigation measures under implementation. In Costa Rica, the national population and housing census of 1984 was cancelled as funds were diverted into reconstruction and relief operations following the devastating Hurricane Caesar. A mechanism must be developed to guarantee the funds for producing these basic datasets. A more aggressive approach is required for marketing government data and information products. For example, as of September 2002 the National Geographic Institute of Costa Rica still lacked a website, and hence its products are not advertised through the internet. This low-cost measure could provide the necessary funding to ensure the continuation of the 1:10,000 land-use series.

9.1.3 Strategy Development and Cost-Benefit Analysis

According to Zeckhauser and Shepard (1984), the fundamental risk management dilemma is: *Where should we spend whose money to undertake what programmes to save which lives with what probability?* Although there may be ethical objections as well as technical difficulties in putting a price on human lives, it seems that unfortunately this has to be done. Failure to do so implies that decisions are adopted on the basis of property and production. This research has illustrated that despite the need to improve in some areas (see Section 9.2, “Recommendations for Further Research”), it is possible to estimate the financial cost of building and infrastructure damage as well as that associated with casualties. The case study has illustrated the degree to which building losses outweigh human losses. One can conclude that, from a policy point of view, if the priority is to save human lives, the financial losses due to casualties should be given higher weight in a cost-benefit analysis. It has also highlighted the fact that it is meaningless to analyse strategies by considering only these two criteria while overlooking the damage to contents and secondary losses (such as loss of production and costs associated with medical attention and temporary shelter). A multi-disciplinary team would need to be expanded by incorporating both research staff with a background in industrial engineering or business administration for estimating the loss of production. This is a particularly complex topic as it requires resumption times to be determined not only for damage within facilities but also for damage to transport infrastructure, such as rail tracks, roads or bridges.

Prevention

The production of a zonation map is the most useful mechanism for preventing future damage from taking place. An adequate way of handling urban growth in Cartago is to combine the construction bans with a mechanism that guides growth by means of financial incentives according to the levels of expected ground shaking. The application of different construction permit tariffs and annual property taxes is thought to be an effective way of guiding urban growth, as this would have implications for both the developers and future owners.

The local government should also consider the option of applying financial incentives (in the form of lower construction permit tariffs) to promote the development of housing and commercial estates rather than individual buildings. This is highly desirable; it not only cuts down on the human resources and equipment needed for the supervision of construction works, but a higher quality of supervision can also be delivered throughout the areas. The latter can be attributed to the deeper understanding of the buildings' construction process, resulting from the volumes involved. Estates are also desirable as they offer stratification possibilities that can reduce the time spent collecting ground data.

Reduction

In order to decrease the losses and casualties that could occur in existing buildings, apart from evacuation drills, the types of strategies that could be developed for Cartago are basically either physical or functional changes.

Evacuation drills are probably the most cost-effective measure in the field of reducing population risk. In Cartago, however, the issue of evacuation is not such a high priority as it is in cities such as Mexico City, Istanbul or Tokyo. The time it takes most individuals to reach safety is relatively short, as approximately 95% of the buildings are either one or two storeys high. The case study has demonstrated the use of GIS for identifying areas where potential accommodation is available in relation to residential areas.

From the analysis of temporary load design parameters (refer to Table 6.3), one can conclude that the change in use of a building can lead to higher vulnerability. Planning offices should therefore only grant change-of-use permits in cases where the building will have a similar load to that which it was designed for, or where it will be re-strengthened to enable it to cope with the extra load. The change in use of a building should be also considered as a low-cost reduction measure to decrease building vulnerability. If the first floor of a two-storey adobe building is used as a warehouse, the owner could be forced to change the land-use to "residential" in an effort to bring down the temporary loads. Similarly, the changes in land-use can also be used to modify the population densities in certain areas of town. This is easy to achieve for government-owned buildings, otherwise it might involve complex legal procedures and financial compensation. The monitoring of building use change should therefore be one of the priority mechanisms to control and reduce vulnerability. It is thought that the digital image capture method developed as part of this research is an important tool for keeping track of building use changes.

Two physical changes that would be appropriate measures in Cartago are the demolition or retrofitting of buildings. In the case of adobe and un-reinforced masonry buildings, there is unfortunately little that can be done to improve their response. The most obvious starting point is to decrease the load of the roof, as regards both the actual roof material (e.g. clay tiles) and the roof trusses. In the case of Cartago, clay tile roofs have already been replaced by corrugated metal. Replacing the heavy Spanish colonial or early Republican wood trusses with lightweight materials such as metal should be undertaken.

There are measures, however, that, despite not modifying a building's susceptibility to damage, represent low-cost options that can reduce casualties. For example, meshes can be attached to both sides of a wall. They are then fixed together and also fixed to the roof trusses and finally plastered. The time it takes the walls to collapse is extended by a few seconds; this extra time can represent the difference between safe evacuation and death.

The other issue that must be considered in an urban disaster reduction plan is the prioritisation of the work. Due to cash flow and labour supply, it is not possible to demolish or retrofit all the buildings at the same time. The simplest way to prioritise is by type of building; adobe buildings would be demolished first, followed by un-reinforced masonry buildings, while reinforced concrete frames without proper seismic resistant design would have high priority for re-strengthening (refer to Figure 9.1 for an illustration of steel bracing used for strengthening an existing frame).

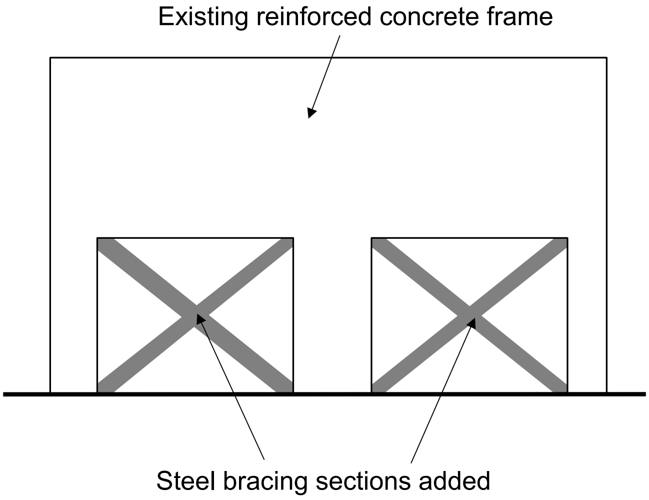

Figure 9.1: Steel Bracing for Reinforcing Concrete Frames without Proper Seismic Resistant Design

However, from the point of view of casualties, the parameter of population density should be considered alongside the building type, and therefore it is possible to prioritise the various measures by applying simple multi-criteria evaluation techniques.

A public-private partnership is seen as a mechanism that could be used in Cartago for redeveloping areas that concentrate adobe and un-reinforced masonry buildings. This partnership could focus on the redevelopment of the city centre, where there is a high concentration of these types of buildings. Due to their proximity to the market, land in this area has a high commercial value. The role of the government in this partnership would be to make the land available by means of expropriation. Private sector developers would have the chance to bid for the land and redevelop it according to guidelines drawn up by the local government. In this way, a considerable portion of these weak buildings would be demolished, thus lowering building and population risk.

Diffusion

If the production of risk scenarios and the development of strategies on the urban disaster management of Cartago are important, perhaps even more relevant are the mechanisms for the diffusion of this information amongst the general public. Children and teenagers are easily reached in schools; reaching the rest of the population is considerably more difficult. In Cartago, the Catholic Church could play an important role in the implementation of awareness campaigns. The attendance at mass on weekends is high, as the inhabitants of this city are devoted Christians. As an institution, it could provide a forum for discussion on the changing attitude of the Church in relation to the perception of the cause of hazards. As a building visited by large numbers of people, it could provide a space for the display and distribution of maps and leaflets.

It is important to keep in mind that it appears that some politicians would rather hide risk assessments from fear that their dissemination might deter foreign investors. It means therefore that technocrats and urban planners must devise mechanisms to make sure that the information is not only produced but also disseminated as widely as appropriate.

9.1.4 The Multi-Hazard Probability-Based Approach to Disaster Management

A multi-hazard probability-based approach to disaster management must be adopted in Cartago – in other words, an integrated strategy in which first the bigger picture is assessed before working out the details of the individual strategies. There are basically two very important weaknesses in the way risk is addressed, the first relates to lack of awareness of the “secondary domino effects” while the second relates to how to address the use of probability to integrate all existing scenarios. Unless probability is brought into the analysis, very misleading conclusions can be drawn and funds will most likely be spent inadequately.

Regarding the domino effects in Cartago, an earthquake can trigger a landslide upstream at San Blas and this can in turn trigger a mudslide. On the other hand, due to the large number of wooden buildings and the existence of an oil pipeline situated to the north of the study area, the fire scenario should also be generated. This post-earthquake fire scenario should be developed by staff from the fire department (which in Costa Rica is attached to the National Insurance Institute), as these are the experts on ignition sources and fire spread. Similarly, experts in ground failure and hydrology should generate the mudflow scenario.

The three scenarios should be combined in order to estimate the maximum possible damage throughout the city in what could be described as the “what if everything goes wrong scenario”. Similar to the basic analysis carried out in the case study, the resources of emergency and health facilities could be analysed against this scenario to identify whether they would be able to “cope” or whether it would be necessary to pool resources from outside the city boundaries.

Hazard probability is possibly one of the most important factors contributing to the successful generation of mitigation strategies as the recurrence period converts absolute figures into relative ones, which can then be interpreted more easily. Probability data could identify, for example, whether the yearly flood (which only features in the local newspaper) causes more annual losses than a mudflow (which takes place every 50 years but features on the international newspapers and attracts foreign rescue teams and donations). Although planners tend to be more comfortable with annual or 10-yearly figures, a compromise might be needed as pragmatism dictates that politicians would favour annual and four-yearly analyses as these correlate with the duration of one fiscal year and one term in office. Therefore it is probably easier for them to relate to these time frames than to the decade.

9.1.5 Information Infrastructure and Networks

Since natural disasters respect neither administrative nor political boundaries, institutions must network, not only in terms of technical and human resources but also in terms of data and information products. This implies that disaster management requires a change in attitude as government institutions tend to work in isolation. Additionally within Costa Rican organisations, there is a culture of ownership of data by individuals.

From the analysis of the legal framework of Costa Rica, it was concluded that it is reasonably adequate in terms of setting responsibilities and making individuals and institutions accountable for their acts – or lack of them. Efforts at this point in time should therefore be concentrated on policy regarding the establishment of both a national spatial infrastructure and a disaster information network. The establishment of these two entities would lead to an improvement in disaster management, thus decreasing risk.

Rather than establishing its own standards, the national disaster information network should adhere to standards set by the national spatial infrastructure. A Costa Rican national spatial infrastructure should be established around the Central American Geographic Information Project (PROCIG), which has already made some progress in identifying suppliers of spatially-referenced data and information products by surveying 12 government institutions, three non-government organisations and six research centres. The Ministry of Planning and Economic Policy (MIDEPLAN) would be a suitable leader of the national spatial data infrastructure. This institution is the entity responsible for regional planning; it deals with issues such as identifying physical, natural and human assets, as well as developing policy-making in fields such as production and poverty alleviation. The National Commission for the Prevention of and Response to Emergencies (CNE) would be the obvious institution to lead a disaster information network.

Setting up a successful disaster data/information network is one of the greatest challenges faced by the geo-information community in Costa Rica. This requires considerable effort and commitment by the various users and providers of information, as well as clarity on the rights and obligations of all the parties involved. To achieve this objective, there are several important issues that should be addressed:

- A coordinating organisation or committee should be appointed to serve as primary portal of access to national and international networks. MIDEPLAN and CNE appear the most suitable entities for this task. This coordinating entity should also be responsible for semantics, as one of the issues that hampers the disaster management process in Costa Rica is the severe inconsistency in the use of terminology. A review of the legal framework must be performed by this entity to identify confidentiality laws that limit access to datasets. The restrictions on access to the various datasets must be established according to the resolution of data and the type of data user (i.e. government, non-government or private organisation). Security mechanisms must therefore be designed to limit access to certain datasets by particular users. This issue is particularly important if it is intended to grant access to data and information products through the World Wide Web. Parallel to this activity, there should be an initiative to review confidentiality laws from the point of view of both adequacy and any misinterpretation that may be currently taking place. It has been observed that, for example, access to high-resolution census datasets is denied by the information centre at the National Statistics and Census Bureau (INEC) due to a misinterpretation of the law. As far as possible, data sharing barriers must be abolished or at least lowered.

- Users (and potential users) of data must be identified in both the public and private sectors. Within the private sector, the involvement of the real estate, insurance and building manufacturing sectors is important. These sectors possess vast knowledge regarding building and population vulnerability, and in some cases they have conducted the most comprehensive studies on building and population risk. Financial resources are often wasted, as in Costa Rica it is common that several organisations conduct studies of the same type. In other words, a network would be useful for preventing duplication of efforts. The case study in Cartago has highlighted the costs involved in developing building inventories. In the case of the insurance and real estate sectors, they should also be seen as potential purchasers of data that could contribute to the financial sustainability of the risk assessment and its periodic update. A pricing policy must therefore be developed to ensure cost-recovery of data production.

- A user-needs assessment must be conducted in each organisation to identify the relevant datasets that support each of the tasks carried out by the institution. Ideally, the user-needs assessment should target decision-makers as well as geo-information professionals and technicians. Of particular importance is the identification of the minimum spatio-temporal standards required by each organisation. For those organisations that require "coarser" data supplied less frequently, it should be established whether aggregation is an acceptable option.

- The list of institutions surveyed by PROCIG highlights the fact that the private sector is not regarded as a potential data provider, but simply as a data user and purchaser. Data providers (and potential ones) must be identified in both the public and private sectors and the spatio-temporal characteristics of the datasets that they presently produce must be identified. In cases where several organisations currently duplicate efforts by producing the same data layers, the work should be split amongst the various providers. An analysis of the strengths and weaknesses of these providers is necessary to distribute the work in a way that ensures the best possible results in terms of quality and time. Agreement must be achieved in terms of interoperability, metadata and classification standards, as well as deadlines for delivery of the datasets, which each organisation will be responsible for producing. The government should be responsible for setting data standards and quality control.

- Communication technologies such as the World Wide Web could be used for the diffusion of information about the network and available products, as well as for the dissemination itself. A website should be designed to provide details about available datasets and their metadata, as well as pricing policy and regulations on use. Such a website could also act as the primary platform for access to the datasets by means of downloading – although since large files require high bandwidth, access to some files might only be feasible through CD-Roms. One must be aware that, although at present most government organisations and private companies have access to internet, according to Martínez (2001) it is estimated that only approximately 4% of the Costa Rican public officially subscribe to it. One of the greatest challenges relates to the access of small community-based organisations (CBOs), such as the local emergency committees, to this "communication superhighway" as these groups constitute the warhorses of disaster management in Costa Rica.

9.1.6 The Role of Academia

A considerable amount of research has been conducted on hazard phenomena and their zonation. In comparison, smaller amounts of research have been carried out in the field of vulnerability and the application of risk assessments for urban disaster management and emergency response. A particularly serious weakness relates to the development of damage curves for assessing the risk of the elements. There must be sustained efforts in raising awareness both within the engineering community and within organisations that could provide the funding for undertaking such research. Disaster managers should play a leading role in ensuring that these topics are included in the agendas of research and funding organisations.

On the other hand, academics must engage in disaster management along with other disaster planners and “responders”. During the Global Disaster Information Network Conference in Rome in 2002, for example, a consensus seemed to exist regarding a lack of communication, particularly between the academic community and emergency relief organisations. A possible way forward is to establish a system by which disaster managers and emergency relief workers draft research questions of relevance and the academic community engages in the topics that are thought to be of sufficient scientific content to be “researchable”. This type of cooperation would promote a balance between technology-driven and problem-driven research.

9.2 RECOMMENDATIONS FOR FURTHER RESEARCH

This thesis has illustrated several fields where further research is required. The following are four fields that provide challenging and relevant research opportunities:

1. Development of vulnerability functions and classifications of buildings to enable multi-hazard risk assessments to be conducted rather than individual hazard risk assessments. This type of research requires people with a background in structural engineering, particularly engineers that have been part of earthquake damage reconnaissance teams. One aspect to consider is the need to develop guidelines to enable surveyors to distinguish between building types of similar external appearance.

2. Modelling of population mobility throughout the day. This topic requires researchers with a background in urban or human geography, particularly those with experience of census data and household surveys.

3. Estimating loss of production is probably one of the most important topics in need of research. It is complex as it first requires civil and architectural engineers to conduct research into the estimation of time required to rehabilitate or reconstruct damaged

buildings and infrastructure such as roads, rail tracks and bridges. In a second stage, researchers with a background in industrial engineering and business management are required to investigate the estimation of the loss suffered through interrupted production (due to casualties and building damage), the lack of transport means and the loss of market.

4. Integration of portable devices and their use in an environment of multiple users and time constraints for field data collection. More research is needed into linking mobile GIS devices such as palm-top computers (including a review of suitable palm-top GIS software) with GPS and digital video devices. Particular attention should be paid to rapid and straightforward methods of linking the devices and integrating the data collected by the various surveyors. This type of research is required to make it possible for emergency decision-makers to obtain the necessary information products as quickly as possible.

Several of these topics not only require multi-disciplinary research teams but also require partnerships with other research organisations to be established.

9.3 FINAL REMARKS

When interpreting risk or damage maps, planners must be aware that these do not offer predictions. Due to the uncertainty of the knowledge available on hazards, their recurrence patterns and their effects, all loss estimates are merely extrapolations into the future of the observed statistical distribution of occurrences of hazards and their effects in the past.

This situation is highlighted by the UN Disaster Management Training Programme (United Nations Department of Humanitarian Affairs 1994).

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Appendix I: MODIFIED MERCALLI INTENSITY SCALE

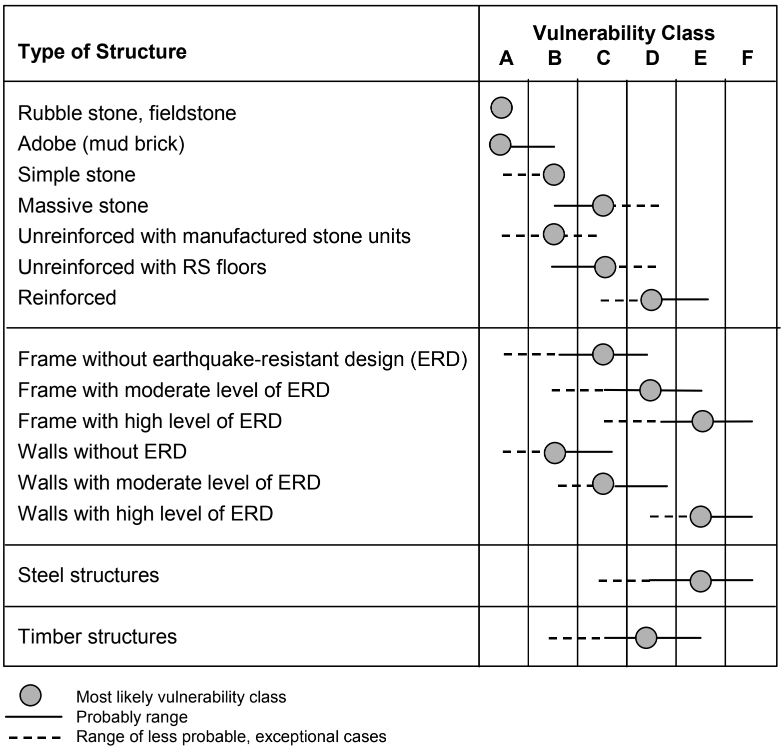
Source: (Smith 1996)

MMI	**Description**	**Average PGA** g = gravity (9.8 m s^2)
I	Not felt except by a very few under especially favourable circumstances.	-
II	Felt only be a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	-
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognise it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated.	-
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.	0.015g – 0.02g
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.	0.03g – 0.04g
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	0.06g – 0.07g
VII	Everybody runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.	0.10g – 0.15g
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.	0.25g – 0.30g
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	0.50g – 0.55g
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.	above 0.60g
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bend greatly.	
XII	Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.	

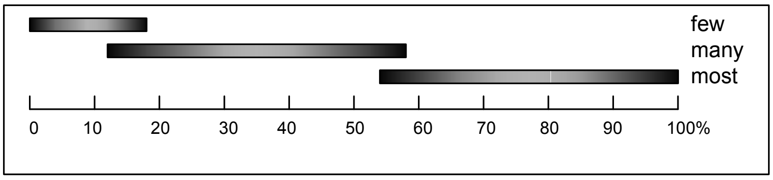
Appendix II: EUROPEAN MACROSEISMIC SCALE 1998

Source: (European Seismological Commission 1998)

II.I Vulnerability Table



II.II Definitions of Quantity



II.III Definitions of Intensity Scales

	Effects on Humans	Effects on Objects and Nature	Damage to Buildings
I	Not felt, even under the most favourable circumstances	No effect	No damage
II	The tremor is felt only at isolated instances (<1%) of individuals at rest and in a specially receptive position indoors.	No effect	No damage

III	The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling.	Hanging objects swing slightly.	No damage.
IV	The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair, etc.	China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.	No damage.
V	The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.	Hanging objects swing considerably. China and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. In a few cases window panes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.	Damage of grade 1 to a few buildings of vulnerability class (vc) A and B.
VI	Felt by most indoors and by many outdoors. A few persons loose their balance. Many people are frightened and run outdoors.	Small objects or ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.	Damage of grade 1 is sustained by many buildings of *vc* A and B; a few of class A and B suffer damage of grade 2; a few of class C suffer damage of grade 1.
VII	Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.	Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.	Many buildings of *vc* A suffer damage of grade 3; a few of grade 4. Many buildings of *vc* B suffer damage of grade 2; a few of grade 3. A few buildings of *vc* C sustain damage of grade 2. A few buildings of *vc* D sustain damage of grade 1.
VIII	Many people find it difficult to stand, even outdoors.	Furniture may be overturned. Objects like TV sets, typewriters, etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.	Many buildings of *vc* A suffer damage of grade 4; a few of grade 5. Many buildings of *vc* B suffer damage of grade 3; a few of grade 4. Many buildings of *vc* C suffer damage of grade 2; a few of grade 3. A few buildings of *vc* D sustain damage of grade 2.
IX	General panic. People may be forcibly thrown to the ground.	Many monuments and columns fall or are twisted. Waves are seen on soft ground.	Many buildings of *vc* A sustain damage of grade 5. Many buildings of *vc* B suffer damage of grade 4; a few of grade 5. Many buildings of *vc* C suffer damage of grade 3; a few of grade 4. Many buildings of *vc* D suffer damage of grade 2; a few of grade 3. A few buildings of *vc* E sustain damage of grade 2.
X			Most buildings of *vc* A sustain damage of grade 5. Many buildings of *vc* B sustain damage of grade 5. Many buildings of *vc* C suffer damage of grade 4; a few of grade 5. Many buildings of

			vc D suffer damage of grade 3; a few of grade 4. Many buildings of *vc* E suffer damage of grade 2; a few of grade 3. A few buildings of *vc* F sustain damage of grade 2.
XI			Most buildings of *vc* B sustain damage of grade 5. Most buildings of *vc* C suffer damage of grade 4; many of grade 5. Many buildings of *vc* D suffer damage of grade 4; a few of grade 5. Many buildings of *vc* E suffer damage of grade 3; a few of grade 4. Many buildings of *vc* F suffer damage of grade 2; a few of grade 3.
XII			All buildings of *vc* A, B and practically all of C are destroyed. Most buildings of *vc* D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

II.IV Classification of Damage

Masonry Buildings

Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)
Hair-line cracks in very few walls.
Fall of small pieces of plaster only.
Fall of loose stones from upper parts of buildings in very few cases.

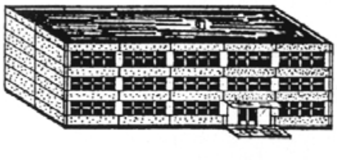
Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)
Cracks in many walls.
Fall of fairly large pieces of plaster.
Partial collapse of chimneys.

Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)
Large and extensive cracks in most walls.
Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls.

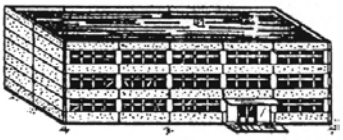
Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)
Serious failure of walls' partial structural failure of roofs and floors.

Grade 5: Destruction (very heavy structural damage)
Total or near total collapse

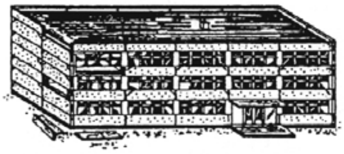
Reinforced Concrete Buildings



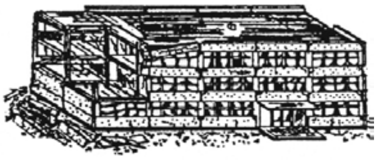
Grade 1: Negligible to slight damage
(no structural damage, slight non-structural damage)
Fine cracks in plaster over frame members or in walls at the base.
Fine cracks in partitions and infills.



Grade 2: Moderate damage
(slight structural damage, moderate non-structural damage)
Cracks in columns and beams of frames and in structural walls.
Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.



Grade 3: Substantial to heavy damage
(moderate structural damage, heavy non-structural damage)
Cracks in columns and beam column joints or frames at the base and at joints of coupled walls. Spalling of concrete cover, bucking of reinforced rods.
Large cracks in partition and infill walls, failure of individual infill panels.

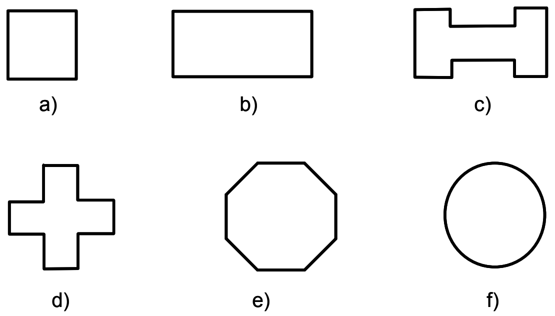


Grade 4: Very heavy damage
(heavy structural damage, very heavy non-structural damage)
Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns.
Collapse of a few columns or of a single upper floor.

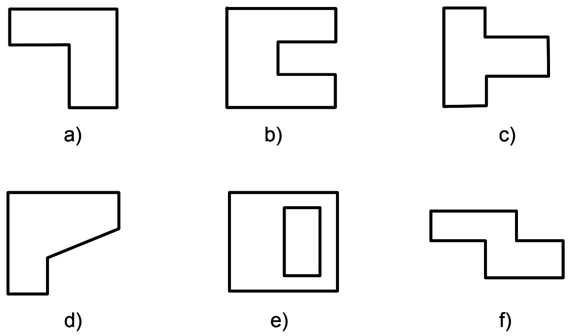
Grade 5: Destruction
(very heavy structural damage)
Collapse of ground floor or parts (I.e. wings) of buildings.

Appendix III: BUILDING CONFIGURATION

Source: Sauter and Shah (1978)

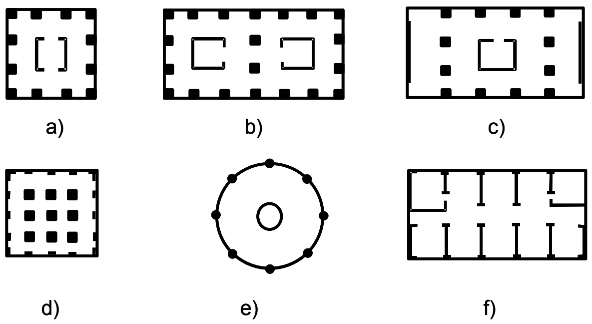


A) Perfect Symmetry

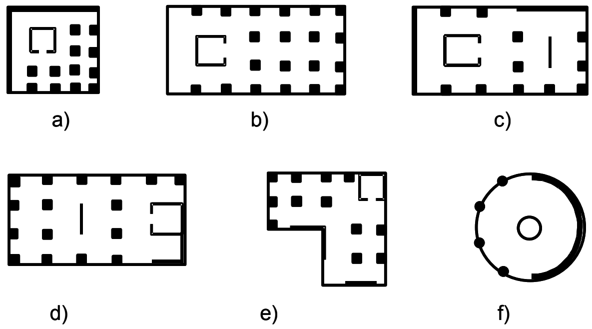


B) Asymmetric

Geometry of Floor Plan

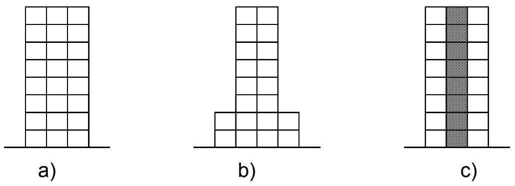


A) Perfect Symmetry

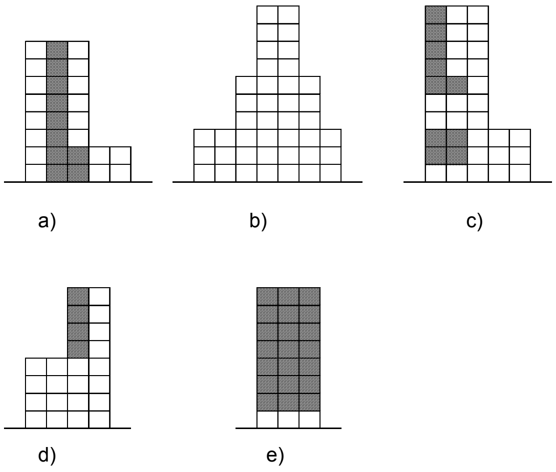


B) Asymmetric

Distribution of Rigidity



A) Regular



B) Irregular

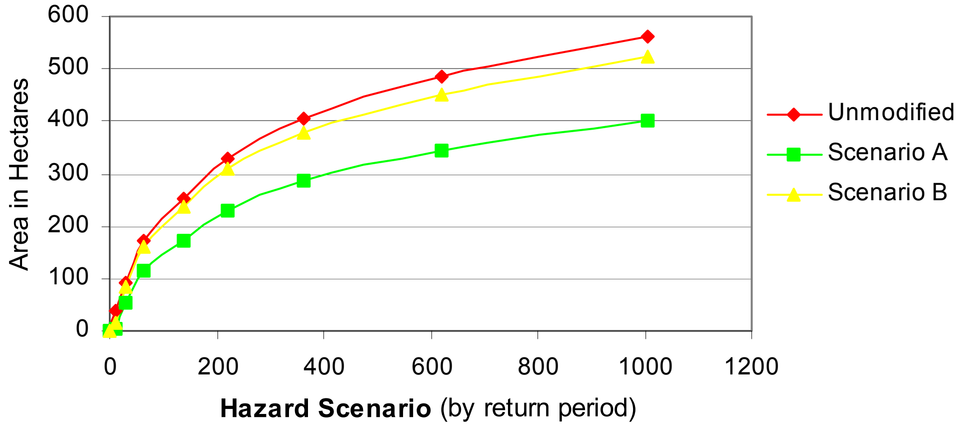
Regularity of Shape in Vertical Plane

Appendix IV: DAY/NIGHT CASUALTIES

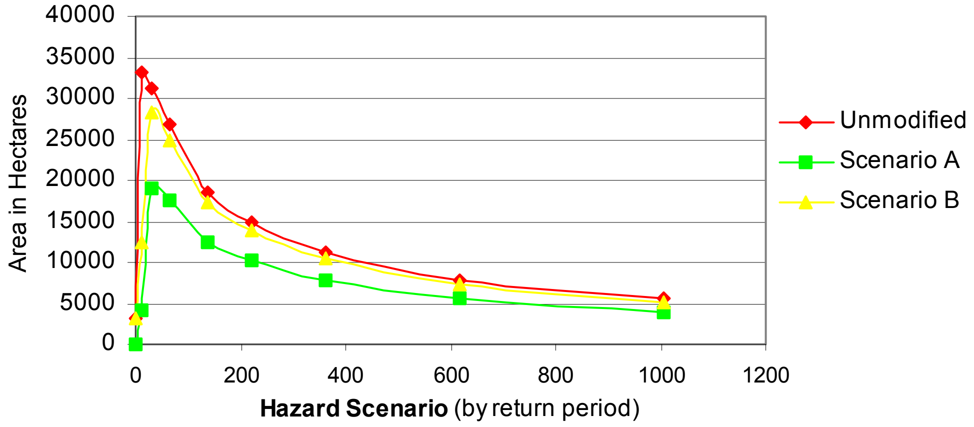
DAY									
Return Period	**Unmodified**			**Scenario A**			**Scenario B**		
	Minor	**Major**	**Deaths**	**Minor**	**Major**	**Deaths**	**Minor**	**Major**	**Deaths**
1.00	1.96	0.26	0.07	0.00	0.00	0.00	1.96	0.26	0.07
11.00	3.98	4.51	1.13	3.98	0.53	0.13	3.98	0.53	0.13
29.00	14.85	6.62	1.66	3.98	4.28	1.33	14.85	4.83	1.66
64.00	235.27	33.93	8.48	3.98	4.79	4.84	63.41	33.04	8.48
137.00	455.70	61.23	15.31	3.98	5.30	8.35	111.97	61.25	15.31
227.00	1247.75	166.72	41.68	4.08	17.23	9.58	201.10	150.92	37.73
363.00	2039.80	272.21	68.06	4.18	29.16	10.80	290.24	240.58	60.14
619.00	2831.86	377.70	94.43	4.27	41.09	12.03	379.37	330.24	82.56
1007.00	3623.91	483.19	120.80	4.37	53.01	13.25	468.50	419.91	104.98
	4227.90			70.64			993.38		

NIGHT									
Return Period	**Unmodified**			**Scenario A**			**Scenario B**		
	Minor	**Major**	**Deaths**	**Minor**	**Major**	**Deaths**	**Minor**	**Major**	**Deaths**
1.00	1.67	0.22	0.00	0.00	0.00	0.00	1.67	0.22	0.00
11.00	3.70	3.53	0.84	3.70	0.50	0.00	3.70	0.50	0.00
29.00	12.13	5.96	1.49	3.70	3.63	1.23	12.13	4.45	1.49
64.00	206.63	30.00	7.50	3.70	4.29	5.18	76.16	29.24	7.50
137.00	401.13	54.03	13.51	3.70	4.94	9.14	140.18	54.03	13.51
227.00	1106.66	151.30	37.83	4.08	16.02	9.93	212.00	128.50	32.13
363.00	1812.18	248.56	62.14	4.47	27.10	10.72	283.83	202.97	50.75
619.00	2517.71	345.83	86.46	4.86	38.18	11.51	355.65	277.44	69.36
1007.00	3223.23	443.10	110.78	5.25	49.26	12.31	427.47	351.90	87.98

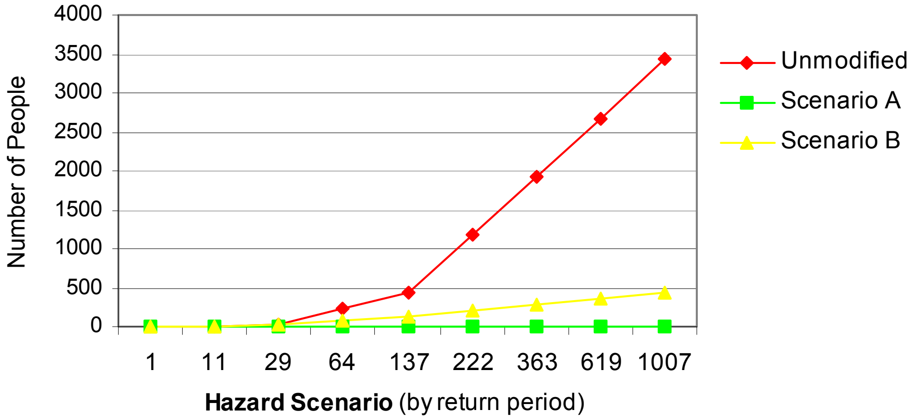
Appendix V: DAMAGE BY PROBABILITY SCENARIO



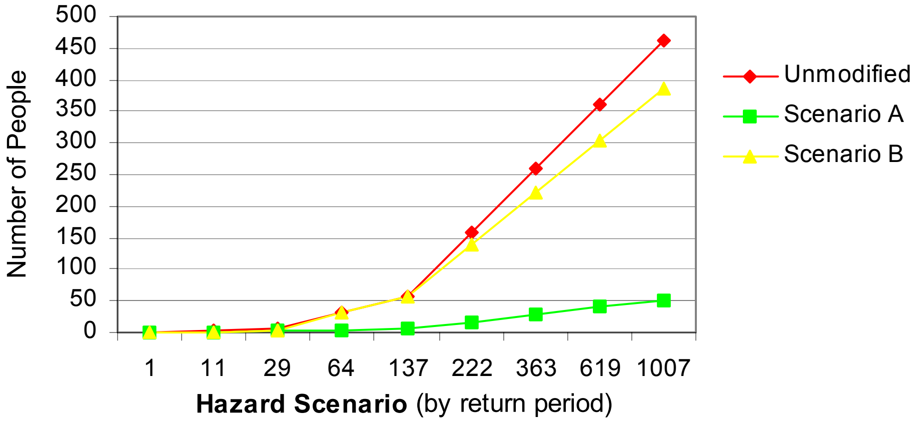
Total Building Damage



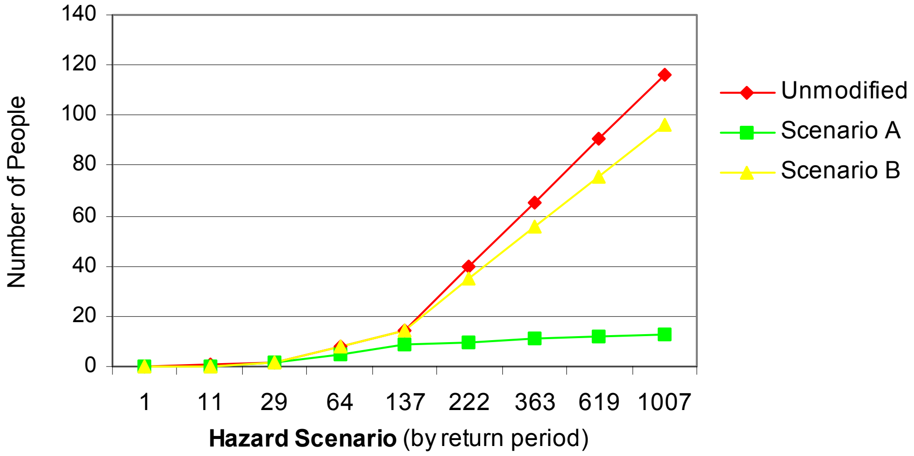
Annual Building Damage



Minor Casualties

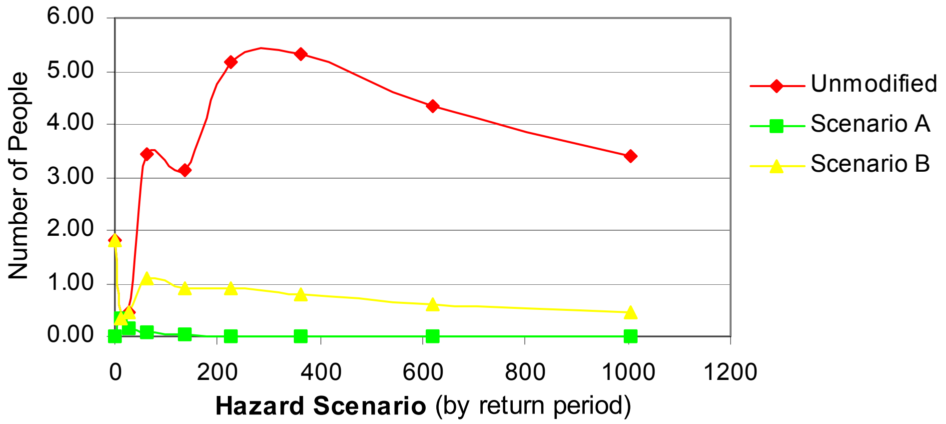


Major Casualties

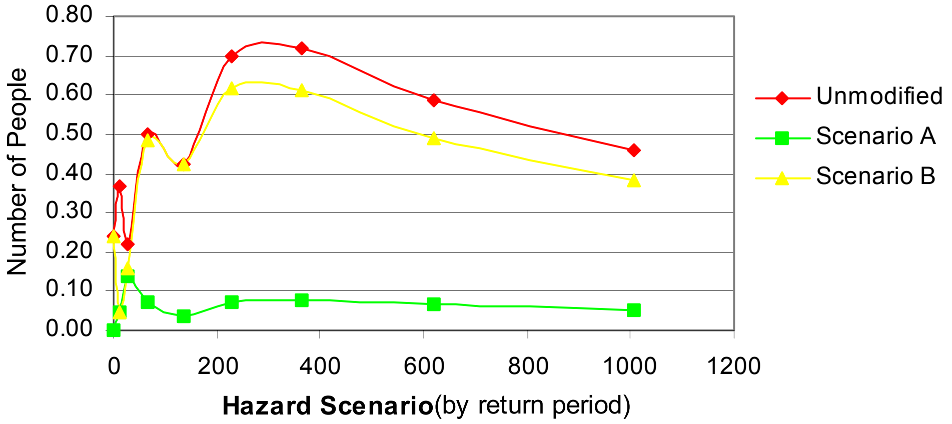


Deaths

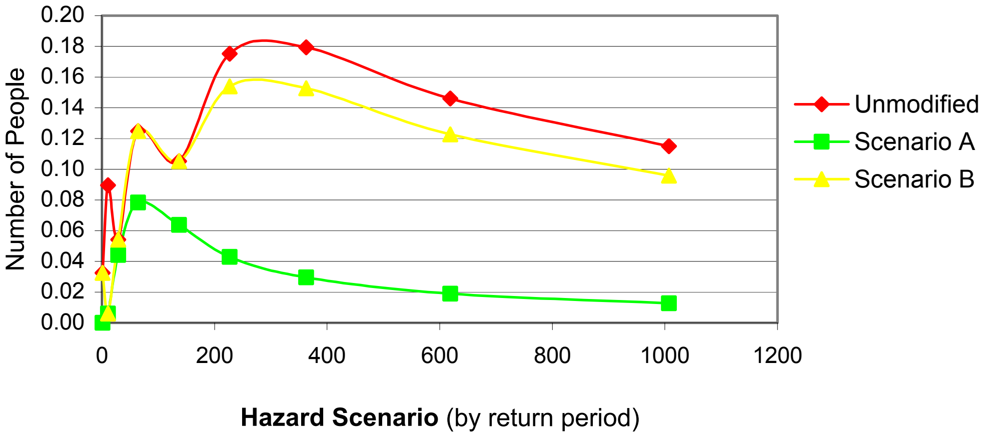
Total Casualties (by injury class) by Mitigation Scenario



Minor Injuries



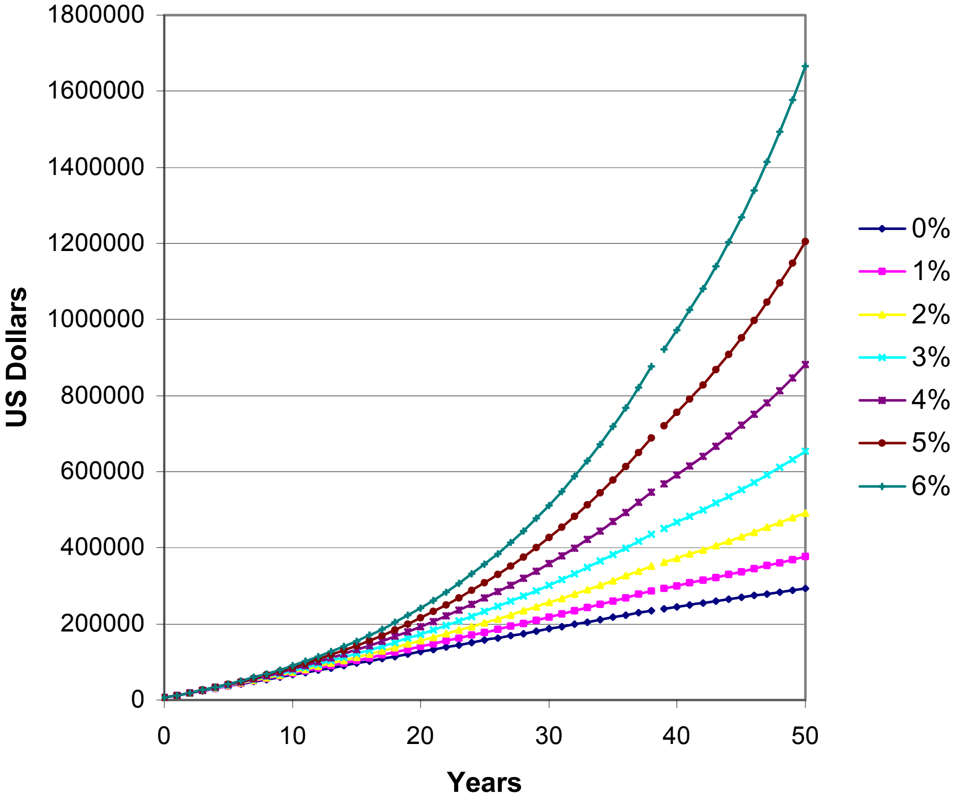
Major Injuries



Deaths

Annual Casualties (by injury class) by Mitigation Scenario

Appendix VI: CALCULATION OF HUMAN CAPITAL



Increase in Human Capital Over Time at Various Rates of Inflation

Based on:

- Average population age of 27 (Instituto Nacional de Estadística y Censos 2001),
- Retirement at 65,
- Life expectancy of 77 (Instituto Nacional de Estadística y Censos 2001),
- Monthly income of 442 US$ (Ministerio de Planificación y Política Económica 2002),
- Pension of 80% of last salary.

Summary

Natural hazards pose a threat to population, its goods and the environment. Urban areas are particularly vulnerable not only because of the concentration of population but due to the interplay that exists between people, buildings, and technological systems. Disasters have the potential to destroy decades of investment and effort, and cause the deviation of resources intended for primary tasks such as education, health and infrastructure. Disaster management is therefore an important component of urban planning and management as disasters pose a serious threat to sustainable development.

There are basically three very important weaknesses in the way disaster management is currently being carried out. The first relates to the reliance upon hazard zonations alone rather than using risk as input for the selection and prioritisation of mitigation strategies. This is unfortunately in part due to the lack of empirical-historical data on damage and due to the high costs of generating and updating building inventories. The second relates to the reliance upon response rather than a concerted effort in both the pre-disaster and the post-disaster phases. The last relates to the lack of disaster information networks which co-ordinate efforts amongst the many institutions involved.

The case of the Costa Rican city of Cartago was chosen as an example of the challenges that lie ahead in terms of geo-information for urban disaster management. The city provides an interesting case study; it represents a typical example of a medium-sized Costa Rican city that is located in a highly hazard-prone area. Cartago is also representative of a financially constrained local government authority with very basic baseline information where plans are elaborated without proper disaster-related information inputs.

The research addresses building and population risk by integrating a hazard intensity map, damage curves derived from historical damage records and a building inventory. Building damage is classified into several classes for the purpose of assessing the extent of the rehabilitation and reconstruction works. In terms of emergency planning, the damage types are also thought to be useful for estimating the number of people in need of temporary accommodation and the likely duration of their displacement. Population risk is considered a function of building damage class. Population risk is classified in three injury levels to assess the capacity of the local health services and identify any need for pooling resources from a wider region. This therefore highlights the regional dimension of disaster management. Probability estimates were used as tool to standardize the various seismic risk scenarios for the purpose of carrying out a cost-benefit analysis. In the case of cities subject to different types of natural hazards, a multi-hazard probability-based approach to disaster management is the key for identifying which risk should be mitigated.

The precision and accuracy of input maps plays a role in the application of the output maps. Combining large-scale maps of elements at risk with small-scale hazard zonations has

obvious weaknesses from the point of view of precision, and it therefore implies that aggregation to higher spatial units (i.e. census tract, district level) is necessary to keep the uncertainties under control. Micro hazard zonations are therefore a pre-requisite for urban disaster management. From an accuracy point of view, the literature review indicated that zonations ought to be calibrated according to the local soil and topography as these can amplify or reduce ground motion considerably. The case study has highlighted the problems caused by a weak earthquake catalogue. In Costa Rica, a single earthquake has dramatically re-shaped the seismic code's zoning map which dictates minimum standards for 1 and 2 storey residential buildings. Unfortunately, this is possibly the weakest link as new earthquakes can be built into the catalogue but there is no way to expand the catalogue backwards.

Population density scenarios should be developed to account for mobility throughout the day and during the weekends. If these scenarios are made available to emergency planners, more lives can be saved as rescue personnel can be directly sent to areas where higher casualties are expected, rather than waiting for the public to ask for help through communications means which might be overloaded or out of order. A survey was conducted to identify criteria that influenced mobility in Cartago. A day population density model was designed on the basis of census data and a land-use map.

For the estimation of financial losses, a model was designed to calculate the lost human earning capacity for three classes of injuries. The building risk was calculated simply on the basis of a flat value per square meter of new construction. However, a threshold was set above which, the buildings are regarded as being in need of demolition. For these buildings, the risk is calculated at 100% of replacement cost.

The data capture methodology hereby developed consists of three main phases: initial classification of the building stock, mission planning and data capture. The initial classification of the building stock is carried out based on emergency response considerations. This classification allows the application of different survey methods to each group, thus maximising existing financial and human resources. It is dependent, however, upon a detailed land use map. This research addressed the data capture that applies to those buildings which are not considered to be key for emergency response. The data capture method constitutes an off-the-shelf low-cost and rapid method involving the combination of digital video (DV), remote sensing (RS) and global positioning systems (GPS) for the data capture phase and the use of a geographic information system (GIS) for the processing and display phases. Remote Sensing is used to identify homogeneous areas, thus reducing the extent of the interpretation effort without hampering the accuracy of the overall results. By resetting the clock information of the DV to match that of the GPS, still images of known location can be produced and input into a GIS for further analysis and manipulation. In the case of seismic building vulnerability, for example, relevant attributes that can be extracted from the image include building material/structural type, number of stories, level of maintenance and age of construction. This video offers a great advantage in the sense that it is multi-functional since the classification and other interpretation issues can be decided *a posteriori*.

An analysis of Costa Rican legal framework identified few gaps in terms of planning regulations, building codes and liability. Although efforts could be made to raise compliance with building codes, this is not considered to be as acute a problem as in other countries. The biggest challenge identified relates to data production, interoperability and barriers on data sharing. These problems could be tackled within the framework of a national disaster information network, which would co-ordinate efforts to avoid duplication, issue standards, make proper diffusion of available data and information products and serve as portal for the exchange of views. This network should be linked to a wider national spatial data infrastructure.

Two basic disaster management measures were proposed on the basis of the case study findings. The first relates to a zonation map for future growth while the second one relates to the cost-benefit analysis of two re-development scenarios. The strategy therefore consists of sustained efforts on both the prevention and the reduction fronts. Regarding the development zonation, a mechanism was proposed by making use of the hazard zonation in combination with the damage curves. It is thought that by imposing different construction permit and property tax rates, development in some areas may be deterred as this system affects both the developer and the owner. Two re-development scenarios were developed; the first one consisted of the demolition of all mud-brick and un-reinforced masonry as well as the bracing of all reinforced concrete frames lacking proper seismic design. The second scenario consisted of only the bracing of the concrete frame buildings. A cost-benefit analysis was conducted to identify the ratios and conclusion was that the more humble option of only bracing the reinforced concrete frames would probably be the favoured option by decision-makers as its cost benefit ratio was lower. The change of use of buildings was also identified as a low-cost vulnerability reduction mechanism worth exploring, although its cost-benefit ratio was not developed due to time and data constraints.

One very important finding of the risk assessment was the large margin by which building risk outweighed population risk. If government policy were to give priority to life over property, a weighting system would have to be incorporated into the cost-benefit analysis.

The greatest strength of GIS proved to be its ability to handle the “what if” type of scenarios. Converting the original forecast into a scenario that, for example, illustrated “what if all reinforced concrete frames without proper seismic design are braced?” was carried out in very little time. This characteristic is probably most useful in emergency response and can therefore contribute to minimize human and property losses.

Samenvatting

Natuurrampen vormen een bedreiging voor bevolking, eigendommen en milieu. Stedelijke gebieden zijn bijzonder kwetsbaar, niet alleen vanwege de bevolkingsconcentratie aldaar maar ook door de wisselwerking tussen bevolking, gebouwen en technologische systemen. Rampen kunnen tientallen jaren van investeringen en inspanningen teniet doen, en maken dat middelen bedoeld voor primaire taken zoals onderwijs, gezondheidszorg en infrastructuur elders moeten worden ingezet. Rampenpreventieplanning is daarom een belangrijke component van stedelijke planning en bestuur want rampen zijn een serieuze bedreiging voor duurzame ontwikkeling.

Er zijn in wezen drie zwakke punten aan te wijzen die een belangrijke rol spelen in de manier waarop thans de rampenpreventieplanning wordt uitgevoerd. Het eerste betreft het vertrouwen op uitsluitend risicozonering in plaats van het gebruiken van risicogegevens als basis voor selectie en prioriteitenstelling van preventiestrategieën. Dit komt ongelukkigerwijs gedeeltelijk voort uit het gebrek aan empirisch-historische gegevens over geleden schade en gedeeltelijk uit de hoge kosten voor het opbouwen en bijhouden van gegevens over de bebouwing. Het tweede betreft het vertrouwen op maatregelen na een ramp in plaats van een systematische aanpak in zowel de fase voor als na de ramp. Het laatste zwakke punt betreft het ontbreken van rampeninformatienetwerken die de inspanningen van de vele betrokken instellingen zouden kunnen coördineren.

De stad Cartago in Costa Rica werd gekozen als voorbeeld van de uitdagingen die op bestuurders afkomen in termen van geo-informatie voor stedelijke rampenpreventieplanning. De stad vormt een interessant onderzoeksobject; het is een typisch voorbeeld van een middelgrote Costa-Ricaanse stad in een gebied waar de kans op een natuurramp groot is. Cartago is ook representatief waar het een lokaal bestuur met beperkte financiële middelen en minimale informatiebronnen betreft dat plannen voor rampenpreventie moet uitwerken zonder over de nodige relevante gegevens te beschikken

Het onderzoek richt zich op risico's voor gebouwen en bevolking door het integreren van een natuurrampenintensiteitskaart, schadegrafieken die afgeleid zijn uit historische schaderapporten, en een gebouweninventarisatie. Schade aan gebouwen is geclassificeerd om de omvang van herstel- of nieuwbouwwerkzaamheden te kunnen vaststellen. Deze schadeklassen worden ook nuttig geacht voor de planning in noodsituaties om in te schatten hoeveel mensen tijdelijk onderdak nodig zullen hebben en hoelang hun evacuatie zal duren. Het risico voor de bevolking wordt beschouwd als een functie van de schadeclassificatie. Het bevolkingsrisico is onderverdeeld in drie letselniveaus om de capaciteit van de lokale gezondheidsdiensten te beoordelen en voorbereid te zijn op de noodzaak om eventueel hulpverleningsdiensten uit een groter gebied in te schakelen. Hiermee wordt de aandacht gevestigd op de regionale dimensie van rampenpreventieplanning. Met behulp van waarschijnlijkheidsschattingen zijn de verschillende seismische risicoscenario's

gestandaardiseerd om kosten-baten-analyses uit te kunnen voeren. Wanneer een stad blootgesteld is aan het risico op uiteenlopende natuurrampen dient een multirisico waarschijnlijkheidsberekening om aan te geven welke risico's verminderd moeten worden.

De juistheid en nauwkeurigheid van de invoerkaarten spelen een rol bij de toepassing van de uitvoerkaarten. Het combineren van grootschalige kaarten van risico-elementen met kleinschalige kaarten van zones met een verhoogd risico op natuurrampen schiet duidelijk tekort op het punt van precisie, en dat impliceert dat aggregatie naar grotere ruimtelijke eenheden (bijvoorbeeld volkstellingsgebieden, districten) noodzakelijk is om de onzekerheden te beperken. Voor stedelijke rampenpreventieplanning is daarom micro-zonering van het risico op een natuurramp een vereiste. Uit literatuuronderzoek blijkt dat uit een oogpunt van nauwkeurigheid de zonering aangepast moet worden met locale informatie over bodemgesteldheid en topografie aangezien door deze factoren de bodembewegingen aanzienlijk vergroot of verkleind kunnen worden. De casestudie legt de nadruk op de problemen veroorzaakt door een zwakke aardbevingcatalogus. In Costa Rica heeft één enkele aardbeving de seismische zoneringskaart met minimum-eisen voor woongebouwen met 1 of 2 verdiepingen dramatisch veranderd. Helaas is dit wellicht de zwakste schakel: weliswaar kunnen nieuwe aardbevingen aan de catalogus toegevoegd worden, maar er bestaat geen manier om de catalogus naar het verleden toe uit te breiden.

Er moeten scenario's voor het meten van de bevolkingsdichtheid ontwikkeld worden die de mobiliteit gedurende de dag en het weekend laten zien. Als zulke scenario's aan rampenpreventieplanners ter beschikking staan kunnen meer levens gered worden. Hulpverleners kunnen meteen naar die gebieden gestuurd worden waar de meeste slachtoffers verwacht worden in plaats van te blijven wachten op verzoeken om hulp via communicatiemiddelen die mogelijkerwijs overbelast of buiten werking zijn. In Cartago werd een onderzoek uitgevoerd om criteria te vinden die van invloed zijn op de mobiliteit. Er werd een model voor de dagelijkse bevolkingsdichtheid ontworpen op basis van volkstellingsgegevens en een grondgebruikskaart.

Om de financiële schade te kunnen schatten werd een model ontworpen om het verlies aan verdiensten van de bevolking te berekenen voor drie klassen van verwondingen. Het risico voor gebouwen werd eenvoudig berekend op basis van een vast bedrag per vierkante meter voor de kosten van nieuwbouw. Daarbij is een drempel vastgesteld; bij overschrijding daarvan werd aangenomen dat het gebouw afgebroken moet worden. Voor die gebouwen werd het risico berekend op basis van de kosten voor volledige nieuwbouw.

De methodologie voor de gegevensverzameling die hierbij ontwikkeld werd bestaat uit drie fasen: een eerste classificatie van de aanwezige gebouwen, planning van het veldwerk en het verzamelen van de gegevens. De aanvankelijke classificatie van de aanwezige gebouwen is gebaseerd op overwegingen die de maatregelen in een noodsituatie beïnvloeden. Deze classificatie maakt het mogelijk verschillende onderzoeksmethoden te gebruiken voor elke groep om zo het gebruik van de aanwezige menselijk en financiële middelen te maximaliseren. Maar dit is wel afhankelijk van de beschikbaarheid van een gedetailleerde grondgebruikskaart. Dit onderzoek richtte zich op het verzamelen van gegevens voor die gebouwen die niet geacht worden een sleutelrol te spelen bij noodhulp (voor gebouwen die wel een sleutelrol spelen wordt door teams van bouwkundig ingenieurs uitgebreid onderzoek gedaan en wiskundige analyses uitgevoerd). De methode is toegankelijk, goedkoop en snel door een combinatie van digitale video (DV), remote sensing (RS) en het global positioning system (GPS) voor de verzameling van de gegevens, en het gebruik van geografische informatie systemen (GIS) voor het verwerken en presenteren van de gegevens. Remote sensing werd gebruikt om homogene gebieden te identificeren. Op die manier wordt de omvang van het interpretatiewerk beperkt zonder de nauwkeurigheid van het uiteindelijk resultaat te verminderen. Door de klok van de DV te synchroniseren met die van de GPS kunnen (stilstaande) beelden verkregen worden met bekende locatie. De informatie van die beelden kan ingevoerd worden in een GIS voor verdere analyse en bewerking. Als een gebouw aardbevingsgevoelig is bijvoorbeeld kunnen relevante attributen uit het beeld gehaald worden zoals bouwmateriaal, bouwtechniek, aantal verdiepingen, onderhoudstoestand en ouderdom. Deze video heeft grote voordelen in die zin dat hij multi-functioneel is omdat over de classificatie en andere interpretatieve overwegingen *a posteriori* een besluit kan worden genomen.

Een analyse van het Costa-Ricaanse wettelijke kader bracht weinig leemtes aan het licht met betrekking tot planningregels, bouwvoorschriften en verantwoordelijkheden. Hoewel het nog mogelijk is ernaar te streven naleving van de bouwvoorschriften te verbeteren, wordt dit niet als een zo dringend probleem beschouwd als in andere landen. Gevonden werd dat de grootste uitdagingen liggen in het verzamelen van gegevens, de uitwisselbaarheid van gegevens en de belemmeringen voor het gezamenlijk gebruik ervan. Deze problemen zouden kunnen worden aangepakt binnen het kader van een nationaal informatienetwerk voor natuurrampen dat pogingen zou coördineren om dubbel werk te voorkomen, standaarden zou bepalen, een goede verspreiding van de beschikbare gegevens en informatieproducten zou bewerkstelligen, en zou dienen voor de uitwisseling van standpunten. Dit netwerk zou gekoppeld moeten zijn aan een bredere nationale infrastructuur voor ruimtelijke gegevens.

Op basis van de bevindingen van deze casestudie zijn voorstellen gedaan voor twee fundamentele maatregelen met betrekking tot rampenbestrijding. Het eerste voorstel betreft een zoneringskaart voor toekomstige groei en het tweede betreft de kosten-baten-analyse van twee scenario's voor de wederopbouw. De strategie houdt dus doorlopende inspanningen in zowel op het preventie- als op het kostenverminderings-front. Wat betreft de zonering voor toekomstige groei werd een werkwijze voorgesteld die gebruik maakt van risicozonering in combinatie met schadegrafieken. Er wordt verondersteld dat door het instellen van verschillende bouwvergunningen en tarieven van onroerendgoedbelasting de ontwikkeling in sommige gebieden kan worden afgeschrikt omdat dit systeem zowel uitwerking heeft op de ontwikkelaar als op de eigenaar. Twee scenario's voor herontwikkeling werden ontworpen; de eerste betreft de afbraak van alle gebouwen bestaande uit leemblokken en ongewapend metselwerk, en de versterking van alle gebouwen van gewapend beton die niet aardbevingsbestendig zijn. Het tweede scenario behelsde uitsluitend de versterking van gebouwen van gewapend beton. Een kosten-baten-analyse werd uitgevoerd om de ratio's te bepalen. De conclusie was dat de meer bescheiden optie van alleen versterking van de gebouwen van gewapend beton waarschijnlijk de voorkeur van de beleidsambtenaren zou hebben omdat de kosten-batenverhouding gunstiger was. Verandering van het gebruik van gebouwen werd ook als een mogelijkheid gezien om tegen lage kosten de kwetsbaarheid te verminderen. Hoewel dit een onderzoek waard is, kon daarvoor niet de kosten-baten-analyse ontwikkeld worden door gebrek aan tijd en gegevens.

Een zeer belangrijke uitkomst van de risico-beoordeling was dat het risico voor de bebouwing zeer veel groter is dan het risico voor de bevolking. Als het overheidsbeleid een hogere prioriteit zou geven aan leven dan aan bezit dan zouden nog wegingsfactoren aan de kosten-baten-analyse moeten worden toegevoegd.

De grootste kracht van GIS bleek de mogelijkheid die het systeem biedt om scenario's van het type "wat als" te hanteren. De omzetting van de oorspronkelijke voorspelling in een scenario dat bijvoorbeeld verduidelijkt "wat als alle gebouwen van gewapend beton die niet ontworpen zijn met het oog op aardbevingen zouden worden versterkt?" kostte bijzonder weinig tijd. Deze eigenschap is waarschijnlijk uiterst nuttig tijdens hulpverlening na rampen en kan er daarom aan bijdragen het verlies van levens en eigendommen te verminderen.

Resumen

Los fenómenos naturales constituyen una amenaza para la población, sus propiedades y para el medio ambiente. Las zonas urbanas son particularmente vulnerables no sólo por la concentración de población sino por la interacción entre población, edificios y sistemas tecnológicos. Los desastres son capaces de destruir décadas de inversión y esfuerzo así como de causar el desvío recursos originalmente destinados a obras primarias tales como la educación, la salud y otras obras de infraestructura. Por lo tanto, la gestión de desastres es un componente importante de la planificación y gestión urbana ya que los desastres constituyen una amenaza seria al desarrollo sostenible.

Existen básicamente tres deficiencias importantes en la forma en que se lleva a cabo el manejo de desastres. La primera se refiere al uso de las zonificaciones de amenaza en lugar de la utilización del riesgo como insumo para la selección y categorización de estrategias de mitigación. Desgraciadamente, esto ocurre en parte por la carencia de datos empírico-históricos sobre daños, así como por los costos elevados de la producción de los inventarios de edificaciones. La segunda se refiere a la utilización de la respuesta como mecanismo de gestión en lugar de esfuerzos conjuntos tanto en la fase pre-desastre como en la post-desastre. La última se refiere a la carencia de redes de información sobre desastres que coordinen los esfuerzos de las muchas instituciones involucradas.

El caso de la ciudad costarricense de Cartago fue escogido como un ejemplo de los retos a futuro en términos de información geográfica para manejo de desastres urbanos. La ciudad ofrece un caso de estudio interesante ya que representa un ejemplo típico de una ciudad costarricense de mediano tamaño localizada en un terreno de amenaza alta. Cartago es también representativa de un gobierno local con limitaciones económicas, el cual cuenta con muy poca información básica y en donde los planes se elaboran sin insumos adecuados en el campo de la información sobre desastres.

La investigación aborda el riesgo de edificios y de la población integrando un mapa de intensidad de amenaza, curvas de daños derivadas de registros históricos y un inventario de elementos en riesgo. El daño a edificaciones se clasifica en varias categorías con el propósito de evaluar la magnitud de las obras necesarias de rehabilitación y reconstrucción. Con relación a la gestión de emergencia, se considera que esta clasificación de daños es útil para estimar el número de personas que estarían necesitadas de alojamiento provisional así como la duración del mismo. El riesgo de la población se considera en función a la clase de daño del edificio. El riesgo de la población se clasifica en tres tipos con el objetivo de evaluar la capacidad de los servicios médicos locales e identificar si hubiera necesidad de solicitar recursos externos, lo cual pone de manifiesto la dimensión regional del manejo de desastres. Se utilizaron datos sobre probabilidad como herramienta para estandarizar los varios escenarios de riesgo sísmico con el propósito de llevar a cabo un estudio de costo-beneficio. En el caso de ciudades sujetas a diferentes tipos de amenazas naturales,

el manejo de desastres debe hacerse bajo un enfoque de amenazas múltiples basado en probabilidad con el fin de identificar el riesgo más problemático.

La precisión y exactitud de los mapas de entrada dicta la aplicación que puedan tener los mapas de salida. La combinación de mapas de elementos en riesgo de escala grande con mapas de zonificación de amenaza de escala pequeña presenta desventajas obvias desde el punto de vista de precisión. Esto lleva a la necesidad de agregar hacia unidades espaciales más grandes (p.e. segmento censal, distrito) para mantener los niveles de incertidumbre bajo control. Por lo tanto, las micro-zonificaciones de amenaza son un pre-requisito para la gestión de desastres en el campo urbano. Con relación a la exactitud, la revisión bibliográfica ha indicado que las zonificaciones deben calibrarse con base en los suelos y topografía locales ya que estos amplifican o reducen considerablemente el movimiento sísmico. El caso de estudio ha ilustrado los problemas ocasionados por un catálogo sísmico limitado. En Costa Rica, un solo terremoto cambió dramáticamente el contenido del mapa de zonificación sísmica utilizado por el código, el cual define los estándares mínimos para viviendas de 1 y 2 pisos. Desgraciadamente, esto es posiblemente el mayor problema en el campo de la evaluación de riesgos ya que los terremotos nuevos pueden incorporarse al catálogo pero no hay forma de expandir este catálogo hacia el pasado.

Los escenarios de densidad de población deben ser desarrollados tomando en cuenta la movilidad a través del día y durante los fines de semana. Si los oficiales de servicios de emergencia contaran con estos escenarios, se podrían salvar más vidas ya que los equipos de emergencia podrían enviarse directamente al campo, sin tener que esperar reportes por medios de comunicación que, de todas formas, estarían posiblemente fuera de servicio o saturados. Se llevó a cabo una serie de entrevistas para identificar los parámetros que influyen la movilidad en Cartago y un modelo de densidad de población diurna fue desarrollado basándose en datos del censo y un mapa de usos del suelo urbano.

Un modelo de pérdida de capacidad de ahorro fue diseñado para la estimación de las pérdidas económicas por concepto de muertos y heridos. El riesgo de las edificaciones fue calculado simplemente con base en un valor único por metro cuadrado de construcción. Sin embargo, un umbral fue establecido sobre el cual, las edificaciones tendrán que ser demolidas. En estos casos, el riesgo se considera como 100% del valor de reposición.

La metodología de captura de datos desarrollada como parte de esta investigación consiste en tres fases: la clasificación inicial de las edificaciones, la preparación de la captura y la captura misma. La clasificación inicial se llevó a cabo bajo el criterio de respuesta a las emergencias y por ende se puede llevar a cabo con base en un mapa detallado de uso de suelos. Esta clasificación permite aplicar métodos diferentes de captura para maximizar los recursos humanos y económicos. Esta investigación se centra en la captura de datos de aquellos edificios que no tienen importancia para labores de emergencia. El método de captura de datos es de bajo costo y consiste en el uso del video digital, la teledetección y los sistemas de posicionamiento global (GPS) para la etapa de captura y el sistema de información geográfica (SIG) para el procesamiento y visualización. La teledetección fue usada para identificar áreas homogéneas, reduciendo la magnitud de la labor de interpretación sin comprometer la exactitud de los resultados globales. Se crearon imágenes estáticas de localización conocida sincronizando el reloj del video digital con respecto al del GPS. Una vez capturadas como imágenes individuales, la interpretación de estas imágenes provee atributos tales como: sistema constructivo y material, número de pisos, nivel de mantenimiento y edad aproximada. Este video ofrece una gran ventaja en el sentido de su multi-funcionalidad ya que la clasificación y otros aspectos de interpretación pueden decidirse *a posteriori*.

El análisis del marco legal de Costa Rica identificó pocos problemas en torno a las regulaciones, códigos y responsabilidad civil. Aunque la conformidad con los códigos podría mejorarse, no se considera como un problema serio si se compara con la situación en otros países del área. Sin embargo, los problemas que se identificaron como de inmediata atención son la producción de datos, su interoperabilidad y las barreras que limitan su acceso. Estos problemas pueden combatirse dentro del marco de una red nacional de información sobre desastres, la cual coordinaría los esfuerzos para evitar duplicidad en la producción de datos, establecería estándares, haría la difusión de los productos existentes y actuaría como portal para el intercambio de ideas. Esta red debería esta ligada a una red superior, una infrastructura nacional de datos espaciales.

Dos medidas de manejo de desastre fueron propuestas con base en los resultados del caso de estudio. La primera se refiere a un mapa de zonificación para expansión urbana mientras que la segunda se refiere al análisis costo-beneficio de dos escenarios de reducción de daños. La estrategia por lo tanto consiste en esfuerzos sostenidos tanto en el campo de la prevención como de la reducción. Con respecto a la zonificación para futura expansión, se propuso el uso de la zonificación de amenazas junto con las curvas de daños, en otras palabras, el riesgo específico. Se consideró que al imponer diferentes tasas tanto para los permisos de construcción como para los impuestos anuales a la propiedad inmueble, se estaría desalentando tanto al desarrollador como al dueño. Dos escenarios de reducción fueron diseñados; el primero consiste en la demolición y reconstrucción de los edificios de adobe y mampostería no confinada así como el refuerzo de los edificios de concreto reforzado de tipo marco dúctil carentes de diseño sísmico adecuado (por medio de estructuras de metal en forma de equis). El segundo escenario consiste únicamente en el refuerzo de las estructuras de marco dúctil descritas anteriormente por el método antes mencionado. Un análisis de costo-beneficio fue llevado a cabo para estimar las relaciones. Se concluyó que el escenario más “humilde” que involucra a los marcos dúctiles únicamente sería probablemente la opción favorecida por aquellos a cargo de la toma de decisiones ya que la relación es más baja. El cambio en el uso de los edificios también fue identificado como una opción de reducción de vulnerabilidad que debería ser considerada, sin embargo, la relación costo-beneficio no fue calculada debido al tiempo disponible y a limitaciones con respecto a los datos.

Un hallazgo importante del caso de estudio fue el grado mínimo que el riesgo por muertes y heridos representa en el riesgo total. Esto significa que si la política gubernamental da prioridad a la vida humana, un sistema de pesos debería ser incorporado en el análisis de costo beneficio.

De la presente investigación se desprende que la mayor ventaja del SIG radica en su habilidad para manejar los escenarios “que ocurre si”. La conversión del pronóstico original en uno escenario que, por ejemplo, ilustra “que ocurre si todos los edificios de concreto reforzado de marco dúctil que carecen de diseño sismo-resistente fueran reforzados?” fue llevada a cabo muy rápidamente. Esta característica es probablemente de mayor utilidad en la respuesta a emergencias y puede por lo tanto minimizar la pérdida de vidas y propiedad.

Curriculum Vitae

Lorena Montoya was born in San José, Costa Rica on the 10th of July, 1967. She attended Saint Francis College secondary school from 1980 to 1984. At the Universidad Autónoma de Centro América (UACA) she obtained her Bachelor's degree in Architecture in 1991, followed by the Licentiate's degree in Architecture in 1993. In 1994 she received professional certification from the Colegio Federado de Ingenieros y Arquitectos de Costa Rica (CFIA). From 1991 to 1998 she was employed at MD Arquitectura S.A. and carried out site selection, design and construction supervision of private and government-funded housing projects. This line of work lead to her in 1995 to enrol in a postgraduate course in Housing, Planning and Building at the Institute for Housing Studies (IHS) in Rotterdam, The Netherlands. Subsequently, she followed a programme on Geo-Information for Urban Planning at the International Institute for Geo-Information Science and Earth Observation (ITC) in Enschede, The Netherlands, where in 1998 she was granted an MSc degree with distinction. In 1998 she was employed by the Project Development Department of the Ministry of Health (CCSS) in Costa Rica to produce a report laying the foundations for the application of GIS for the planning and monitoring of health facilities. Since 2000 she has been a lecturer and a PhD researcher at the Department of Urban and Regional Planning and Geo-Information Management at ITC.