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ORIGINAL RESEARCH PAPER

Saving lives in earthquakes: successes and failures in seismic protection since 1960

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Abstract This paper will look at what we have and have not achieved in reducing the risk to human life from earthquakes in the last 50 years. It will review how success has been achieved in a few parts of the world, and consider what needs to be done by the scientific and engineering community globally to assist in the future task of bringing earthquake risks under control. The first part of the talk will re-examine what we know about the casualties from earthquakes in the last 50 years. Almost 80% of about 1 million deaths turn out to have been caused by just ten great earthquakes, together affecting a tiny proportion of the territory at risk from heavy ground shaking. The disparity between richer and poorer countries is also evident, not only in fatality rates, but also in their rates of change. But the existing casualty database turns out to be a very poor basis for observing such differences, not only because of the small number of lethal events, but also because of the very limited data on causes of death, types and causes of injury. These have been examined in detail in only a few, recent events. All that can be said with certainty is that a few wealthier earthquake-prone countries or regions have made impressive progress in reducing the risk of death from earthquakes, while most of the rest of the world has achieved comparatively little, and in some areas the problem has become much worse. The second part of the paper looks in more detail at what has been achieved country by country. Based on a new expert-group survey of key individuals involved in earthquake risk mitigation, it will examine what are perceived to be the successes and failures of risk mitigation in each country or group of countries. This survey will be used to highlight the achievements of those countries which have successfully tackled their earthquake risk; it will examine the processes of earthquake risk mitigation, from campaigning to retrofitting, and it will consider to what extent the achievement is the result of affluence, scientific and technical activity, political advocacy, public awareness, or the experience of destructive events. It will ask to what extent the approaches pioneered by the global leaders can be adopted by the rest. The final section of the talk will argue that it can be useful to view earthquake

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protection activity as a public health matter to be advanced in a manner similar to globally successful disease-control measures: it will be argued that the key components of such programmes—building in protection; harnessing new technology and creating a safety culture—must be the key components of earthquake protection strategies also. It will consider the contribution which the scientific and engineering community can make to bringing down today's unacceptably high global earthquake risk. It will be suggested that this role is wider than commonly understood and needs to include:

Building-in protection

- Improving and simplifying information available for designers and self-builders of homes and infrastructure.
- Devising and running "building for safety" programmes to support local builders.

Harnessing new technologies

- Developing and testing cost-effective techniques for new construction and retrofit.

Creating a safety culture

- Involvement in raising public awareness.
- Political advocacy to support new legislation and other actions.
- Prioritising action on public buildings, especially schools and hospitals.

Examples of some of these actions will be given. International collaboration is essential to ensure that the resources and expertise available in the richer countries is shared with those most in need of help. And perhaps the most important single task for the engineering community is to counter the widespread fatalistic attitude that future earthquakes are bound to be at least as destructive as those of the past.

Keywords Earthquakes · Building damage · Casualties · Mitigation

1 Introduction: intentions

In the Second Mallet–Milne Lecture, given at the Royal Institution in May 1989, Professor George Housner set out the aims and the plans for the upcoming International Decade for Disaster Reduction IDNDR (1990–2000), with which he was much involved. The interrelated strategies presented, he said, were intended to achieve life-saving and economic advantages during the Decade and beyond. His optimistic assessment was that they would "lay the foundation for continuing achievements in the next century that will yield a world less at risk from the violent forces of nature"(Housner's 1989). And in her closing remarks, D'Souza (1989) emphasised that "the objective was to save lives and to reduce the enormous cost (social and economic) of such destructive events as earthquakes and floods". She closed with the hope that "when this distinguished company gathers again in the year 2000, there will be much to be proud of".

Earthquake engineering is about the protection of life, property and livelihoods from the destructive power of earthquakes, and it concerns every type of action that, as engineers, we take to achieve those aims, whether in the design of new buildings or civil engineering structures, or in the modification of existing ones, or in setting up the human systems needed to create a society safe from earthquakes. Recent

Mallet–Milne lectures have ably reviewed advances in many aspects of the science and technology which underpin our ability to design for safety in earthquakes (Lubkowski 2005).

In this lecture, I propose to return to the theme which lay at the basis of Housner's (1989) lecture, and of the whole IDNDR enterprise, by looking specifically at the question of life safety, and what can be done to improve our apparently rather unsuccessful achievements at protecting lives from earthquakes worldwide. This is not to minimise the importance of the other goals of earthquake engineering. Of course the protection of property and livelihoods are vital goals; and in any case the aims cannot be separated. But it turns out that if we are to give priority to this aim, we immediately have to shift the emphasis away from the already-industrialised and urbanised world to the relatively poor and rapidly urbanising developing countries, from large engineering structures to the housing of the mass of the population, and, to an extent also, away from the creation of new buildings towards the upgrading of what already exists. This is the direction I intend to pursue in this lecture.

It is an aim for which there is much encouragement in the works of both Robert Mallet and John Milne. John Milne's key work "Earthquakes and Other Earth Movements" (Milne 1903) contains an excellent chapter called "The Effects Produced Upon Buildings" which contains much good observation about the performance of small buildings in earthquakes, in Italy, Japan and elsewhere, and ends with a 15-point plan for the safe construction of buildings in earthquake areas, perhaps the first attempt at a Manual on Earthquake-Resistant Design. I have summarised some of Milne's still-pertinent comments in Boxes 1.1 and 1.2.

Box 1.1 Extracts from John Milne, Earthquakes, 5th Edition 1903

Introduction:

In bygone superstitious times lightning and thunder were regarded as supernatural visitations. But as these phenomena became better understood, and men learned how to avoid their destructive power, the superstition was gradually dispelled. Thus it is with Earthquakes: the more clearly they are understood, the more confident in the universality of law will man become, and the more will his mental condition be advanced.

Chapter VI. The effect of earthquakes on Buildings

The subject of this chapter is, from a practical point of view, one of the most important with which a seismologist has to deal. We cannot prevent the occurrence of earthquakes, and unless we avoid earthquake-shaken regions, we have not the means of escaping from them. What we can do, however, is in some degree to protect ourselves. By studying the effects produced by earthquakes upon buildings of different construction and variously situated, we are taught how to avoid or at least to mitigate calamities repeated. The subject is an extensive one, and what is here said about it must be regarded only as a contribution to the work of future writers who may give it the attention it deservedly requires.

Box 1.2 Extracts from John Milne, Earthquakes, 5th Edition 1903

Typical houses for earthquake countries:

From what has now been said about the different buildings found in earthquake countries, it will be seen that if we wish to put up a building able to withstand a severe shaking, we have before us structures of two types. One of these types may be compared with a steel box, which, even were it rolled down a high mountain, would suffer but little damage; and the other, with a wicker basket, which would equally withstand so severe a test. Both of these types may be to some extent, protected by placing them upon a loose foundation, so that but little momentum enters them at their base.

General conclusions: The following are a few of the more important results which may be drawn from the preceding chapter:

1 In choosing a site for a house find out by the experience of others or experimental investigation the localities which are least disturbed. This will usually be upon the hills, or on hard ground.
2 Avoid loose materials resting on harder strata.
3 If the shakings are definite in direction, place the blank walls parallel to such directions, and the walls with many openings in them at right angles to such directions.
4 Avoid the edges of scarps, bluffs, cuttings, riverbanks, both above and below.
5 Experiment and practice have shown that a building with a basement, and surrounded by an open area, is less liable to destruction than one rising from the surface.
6 As far as possible avoid arch work.
7 So arrange the openings in a wall, that for horizontal stresses the wall shall be of equal strength for all sections at right angles.
8 Place lintels over flat arches of brick or stone.
9 To withstand destructive shocks either rigidly follow one or other of the two systems of constructing an earthquake-proof building. The light building is the cheaper and probably the better.
10 Let walls, chimneys, and piers, have such a form that at any horizontal section they shall offer a resistance sufficient to overcome the effects of the inertia of their parts above the section.
11 If it is a necessity that one portion of a building should have a very different period of vibration to the remainder, as for instance a brick chimney in a wooden house, it would seem advisable either to let these two portions be sufficiently free to have an independent motion, or else they must be bound together with great strength.
12 Avoid heavy-topped roofs and chimneys. If the foundations were free the roof might be heavy
13 In brick or stonework use good cement.
14 Let archways curve into their abutments.
15 Let roofs have a low pitch, and the tiles, especially those upon the ridges, be well secured.

Robert Mallet famously derived his First Principles of Observational Seismology in a Report to the Royal Society on the Great Neapolitan Earthquake of 1857 (Mallet

Fig. 1 The damage to Polla, in Irpinia, in the 1857 earthquake (from frontispiece of Mallet 1862)

Fig. 2 Polla from the same location as Fig. 1 in 1981 after the Irpinia earthquake. Note similarity of building form and construction (photo by author)

1862). He was everywhere acutely aware of the tragedy and its causes, even while trying to pioneer an objective science. He concluded with the belief that if “understanding and skill were applied to the future construction of houses and cities in Southern Italy, few if any human lives need ever again be lost in earthquakes, which must recur, in their ‘times and seasons’ ”. Unhappily, reconstruction, as is so often the case, largely reproduced the form of building that proved so vulnerable in 1857, and when the Irpinia earthquake struck very much the same region in 1980, the patterns of damage were remarkably similar to those Mallet observed in 1857. This can be seen in Figs. 1 and 2, which show the same view of the centre of the village of Polla, first after the 1857 earthquake (from the Frontispiece of Mallet’s book), and then again in 1981, a few months after the Irpinia earthquake, during the author’s visit there. The similarity of building form and building damage is very striking.

This paper is organised into three parts. The first part of the talk will re-examine what we know about the casualties from earthquakes in the last 50 years: it will look in particular at the ten most lethal earthquakes of the period, and assess what we know both about the types of damage caused and the resulting injuries. The second part of the talk will look in more detail at what has been achieved country by country. Based on a new expert-group survey of key individuals involved in earthquake risk mitigation, it will examine what are perceived to be the successes and failures of risk mitigation in each country or group of countries, and discuss how far the successes of some countries can become the model for others, so far less successful. In the final section of the talk an attempt will be made to view earthquake protection activity as a public health matter to be advanced in a manner similar to globally successful disease-control measures. It will be suggested that the key components of such programmes—building in protection, harnessing new technology and creating a safety culture—must be the key components of earthquake protection strategies also. And it will consider a number of specific contributions that the scientific and engineering community could make to bringing down today’s unacceptably high global earthquake risk.

2 A review of casualties in earthquakes since 1960

2.1 Forwards or backwards?

Unhappily, at a global level, our efforts to control and reduce the numbers of casualties in earthquakes do not seem to be making any measurable progress. Numbers of casualties in earthquakes since the beginning of twentieth century are recorded in the CRED database held at the University of Louvain (CRED 2006), and Fig. 3 shows the summarised results by decade. This tells us that, on average, between 1900 and 1960, 19,600 lives were lost as a result of earthquakes each year: in the decade of the 1960s, (a good decade), the number was down to 5,200; in 1970s, largely because of the Tangshan earthquake, it was up again to 42,000; in the two following decades it appeared that we were making progress, with annual death tolls of 5,000 and 10,000. But in the current decade, up to mid 2006, the annual rate has been much higher again, at 66,000 per year. Even allowing for population growth during that period, of around 2% per annum globally, it would be difficult to discern any overall downward trend. Figure 3 shows the variation in annual death rates per million population decade by decade. *The current decade is the worst in the last 50 years.*

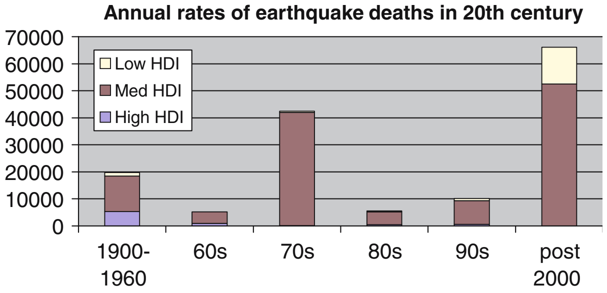

Fig. 3 Annual rates of earthquake deaths since 1900 by decade. The earthquake death rate in the current decade is the worst, and reverses a general downward trend during twentieth century (source, Adapted from CRED 2006)

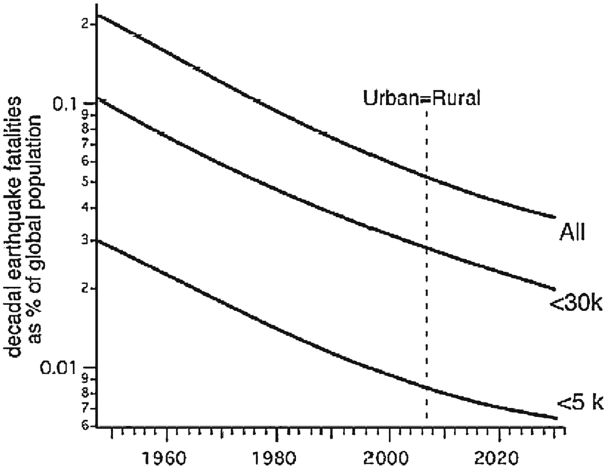

Fig. 4 Smoothed change of decadal earthquake fatalities as % of the instantaneous global population, for three classes of earthquakes: all earthquakes, those with fewer than 30,000 deaths, and those with fewer than 5,000 deaths (source: Bilham 2002). At that time, since 1950 the decline in long-term death rates had been a factor of 2–3 for all three classes of earthquake. The dotted line shows the date, in 2003, when the world's urban population was expected to exceed its rural population

In a 2003 study of the long-term trends in disaster fatality rates in 2003 (Spence 2004), there seemed to be enough evidence to suggest that earthquake death rates, even in the poorer countries, were declining (though deaths from flood and windstorm were rising). A more sophisticated analysis of global earthquake fatality rates conducted at about the same time by Bilham (2002), also showed a decline in fatality rate as a percentage of instantaneous population, by a factor of 2 or 3 since 1950. He separated three classes of events, those killing less than 5,000, those killing less than 30,000, and the giant earthquakes killing more than 30,000: looking at the long-term trends, the same reduction rate applied to all three groups (Fig. 4). However, Bilham also showed an analysis of the frequency of events against the number of casualties (Fig. 5), and argued from this that there are likely to be missing large-fatality events, which in the future could be much more severe than those of the past because of the recent rapid development of so many huge cities in the developing countries. In the time since Bilham's study there has not been a "million-casualty" earthquake of the type he suggests may be possible, but the huge casualties from the events of the last 3 years (Bam, the South Asian Tsunami and Kashmir), have already disposed of the idea of a downward trend. For the global fatality rate, we simply have a large inter-decadal fluctuation.

If global death rates can fluctuate so wildly, those for individual countries are bound to be even more variable—with no major earthquake occurring for decades in

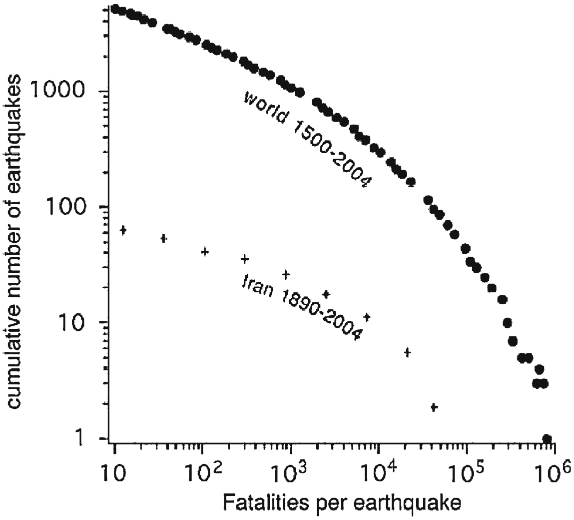

Fig. 5 Million fatality earthquakes in future? The number of earthquakes over the last five centuries which caused a given number of fatalities (this suggests that with a global population of 10 billion, one earthquake in each century could cause a million fatalities. The data from Iran show that the shape of the curve is similar, given enough events. Source: Bilham 2002)

areas of the world known to be seismically active. It is partly for this reason that it is so difficult to create the international consensus for action to deal with the problem.

Earthquakes are not, of course, one of the major causes of death globally. The Global Burden of Disease Survey in 1990 (Murray and Lopez 1997) quantified and ranked causes of death across the world, and some of its findings are shown in Table 1. At around 5–10 deaths per million of population per year, earthquakes kill in a year fewer people than die in traffic accidents or from TB in 1 day.

But global figures tend to be misleading. What they obscure is that the average earthquake risk in some parts of the world, particularly some of its fastest-growing cities, is many times higher than the global average, and may be increasing rapidly. Conversely, earthquake risks in some other parts of the world have genuinely been reduced over the last 40–50 years. It is in this first group that there is the most urgent need for action; and perhaps the way in which that action can be most effectively brought about can be understood by looking at the second group.

A somewhat more detailed analysis of what is known about earthquake deaths and their causes in countries or groups of countries may thus help us to understand how best to tackle the problem. In particular:

- what are the differences between rich and poor countries?
- what are the causes of death in earthquakes?

2.2 Earthquake death rates by country

A comparison can be made of casualty rates in earthquakes in different countries over time, using CRED's EM-DAT database (CRED 2006). It is instructive first to compare the performance of those countries which appear in the list of better developed countries in the UN Development Report (the High Human Develop-

Table 1 Global causes of death in 1990

Cause of death	Numbers of deaths ($\times 10^3$)	Numbers of deaths ($\times 10^3$)	Proportion of all deaths	Proportion of all deaths from unintentional injuries
All causes	50,467			
Group 1: communicable diseases, maternal, perinatal and nutritional disorders	17,241		34%	
Group 2: non-communicable diseases	28,141		56%	
Group 3: intentional and unintentional injuries	5,084		10%	
Of which: unintentional injuries		3,233	6%	
Deaths from road traffic accidents		999		30.9%
Deaths in all natural disasters		43		1.3%
Deaths in earthquakes		10		0.3%

Deaths from unintentional injuries constitute 6% of all deaths, and deaths in earthquakes represent only 0.3% of these (source: adapted from the Global Burden of Disease Survey, Murray and Lopez 1997)

ment Index counties)[1] with those with medium or low HDI. With a knowledge of population growth rates we can make this comparison on the basis of death rates per million population, which makes adjustment for the much more rapidly growing populations of the less developed countries. The results are shown in Figs. 6 and 7. The comparative success of the countries with high HDI, where deaths rates in recent decades have been a very small fraction of those before 1960, is evident from Fig. 6. Figure 7 shows, in contrast, the situation in the poorer countries (about 75% of the world's population) where beneath the decadal fluctuation there appears to be no progress.

Comparable figures are shown for some individual countries in Table 2. Table 2 compares annual death rates in the USA, Japan and Iran in three time periods—pre 1960, 1960s and 1970s and post 1980. This comparison is even more startling. While the USA and Japan have apparently made sustained progress (Japan's of course blighted by the 1995 Kobe earthquake), Iran's record (even allowing for some under-recording before 1960) has, in contrast, apparently been one of progressive worsening—and this in spite of continuous government action to try to improve building standards.

It is also enlightening to compare progress in earthquake protection with that resulting from public heath campaigns of other types. During the twentieth century spectacular progress was made in combating some causes of death, which were extremely common in the population. Figure 8 shows the smoothed decadal fluctuation of earth-

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[1] The Human Development Index is a measure of a country's state of development which looks beyond pure economic indicators, such as GDP, and considers health, education, nutritional and other factors.

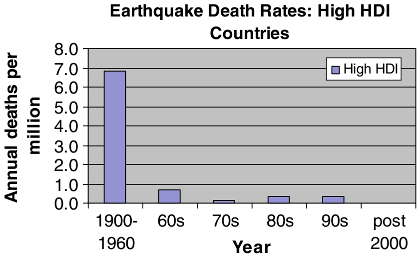


Fig. 6 Annual death rates per million population since 1900: affluent countries. (HDI is the UN's human development index, which measures a country's state of development on a scale which includes measures other than economic). There is clearly huge and sustained improvement since 1960 (source: adapted from CRED 2006)

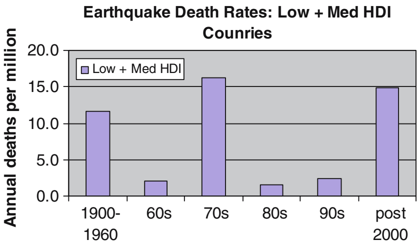


Fig. 7 Annual death rates per million population since 1900: poorer countries. No sustained progress can be seen (source: adapted from CRED 2006)

Table 2 Comparison of annual death rates (per million population) from earthquakes in three countries since 1900 (source: EM-DAT database, CRED 2006)

Period	Pre 1960	1960s and 1970s	Since 1980
USA	41.3	10.2	3.4
Japan	2,670	18	230
Iran	308	2,730	2,970

quake deaths in the twentieth century alongside mortality figures for some particular sectors. For example, in the United States, death rates from infectious diseases were reduced by 80% over the first four decades of twentieth century (Centre for Disease Control 1999); cholera deaths in Asia plummeted between 1970 and 1985 to less than 5% of their previous level (WHO 2006); globally, infant mortality has declined steeply, reaching less than 50% of its pre 1950 levels by 2000 (UNDP 1998; Shackman et al. 2002). And similar levels of reduction in earthquake deaths have been achieved in the richer countries over the decades since 1940. All this shows that, by committed and concerted action, mortality rates can be brought down. What this action has been and what it might be in the future, are the subject of later sections of this paper. Before turning to this, we will investigate what can be learnt from the records about the causes of death in more detail.

2.3 The great killer events: causes of death

More than 80% of all the earthquake deaths which have occurred since 1960 have been the result of just ten great killer events, shown in Table 3. It would help us tackle mortality rates better if we understood the causes of death which are revealed by the history of these events, and others like them. So what do we know about the actual causes of death in these events?

Superficially, the ten events are not alike at all, except in one respect: all of them occurred in poor or middle-income countries or regions. But only two of them occurred in the same country (Iran); two were in Latin America, eight were in Asia. Some

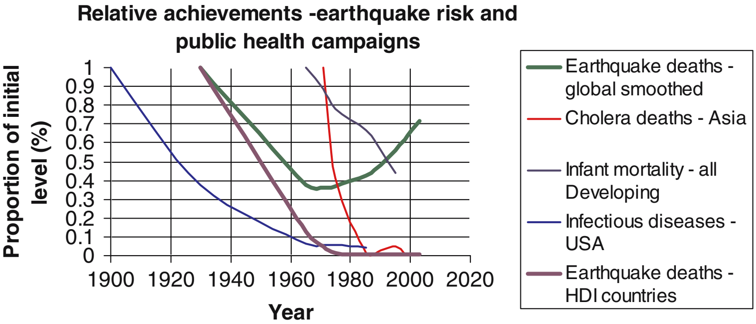


Fig. 8 Relative achievements of earthquake fatality reduction and public health campaigns during twentieth century. The numbers of deaths from each cause are plotted as a proportion of their initial level (sources: Centre for Disease Control 1999; Shackman et al. 2002; WHO 2000; UNDP 1998; CRED 2006)

Table 3 The ten most lethal earthquakes since 1960, and some of their basic characteristics. Between them, these events are responsible for about 80% of all earthquake deaths in the last 50 years (sources: EM-DAT, CRED 2006; USGS 2006)

Earthquake					People		
Event	Country	Date	Local Time	Magnitude (Mw USGS)	Killed	Injured	Homeless
Ancash	Peru	31/05/1970	15:23	7.9	66,794	143,331	–
Guatemala	Guatemala	04/02/1976	03:03	7.5	23,000	77,000	1,166,000
Tangshan	China	28/07/1976	03:42	7.5	242,419	164,581	–
Armenia	Russia	07/12/1988	11:41	6.8	25,000	12,000	530,000
Manjil	Iran	21/06/1990	00:30	7.7	40,000	105,000	105,000
Kocaeli	Turkey	17/08/1999	03:02	7.6	17,437	43,953	600,000
Bhuj	India	26/01/2001	08:46	7.7	13,800	166,812	1,790,000
Bam	Iran	26/12/2003	05:26	6.6	32,000	26,628	45,000
Indian Ocean	Indonesia, Thailand, Sri Lanka	26/12/2004	07:58	9.3	283,100	41,810	1,033,464
Kashmir	Pakistan	08/10/2006	08:50	7.6	73,338	69,142	2,800,000

occurred during daytime, others at night; and although earthquake ground shaking was a factor in all cases, other earthquake hazards were predominant in several cases—landslide, and tsunami. However, unlike the great events of the early twentieth century, fire was not a major cause of death. The following pages will look at each of these events in turn, and we will then assess what the common factors were.

2.3.1 The 31.5.1970 earthquake in Ancash, Peru: Mw = 7.9, 66,000 deaths

This disaster was triggered by a massive Mw = 7.9 (USGS) undersea earthquake in the subduction zone off the Peruvian coast at the boundary of the Nazca and South American plates, which took place at 15.23 local time on Sunday 31 May 1970.

Destructive ground shaking took place over an immense area of the coastal provinces of Ancash and La Libertad, altogether affecting 3,000 km^2 (Fig. 9). In Chimbote, the regional capital, and Casma, also on the coast, about 80–90% of buildings were

Fig. 9 The area of Peru affected by the 31 May 1970 Ancash earthquake (source: Oliver-Smith 1986)

destroyed. Many lives were lost in these coastal towns and also in the towns of the Andean Valley of Callejón de Huaylaz, where the regional capital Huaraz as well as Recuay and Carhuaz were largely destroyed. As in the Guatemala earthquake 6 years later, casualties caused by the collapse of poor quality adobe, as well as other forms of masonry construction, can be assumed to be the major cause of the loss of life in these areas.

But the earthquake is today principally remembered for the immense landslide which was triggered by the earthquake. As recounted by Oliver-Smith (1986), the earthquake shook loose a slab of ice and rock about 800 m wide and 1.2 km long from the northwestern face off Huascaran, Peru's highest mountain. This created a vast landslide which travelled the 16 km to the small valley town of Yungay (Fig. 10a) in less than 4 min, completely burying it as well as several other valley communities, with the loss of almost the entire population. "All that remained of Yungay some 4 min after the earthquake were the tops of four palm trees where the main plaza had been (Fig. 10b), a few survivors huddled in various protected locations in the high ground, and an immense expanse of grey, viscous mud punctuated by huge boulders which appeared to grow in size as the mud settled around them in the days which followed". The thickness of the mud was estimated as 5 m. About 17,000 people, virtually the entire population of Yungay, were buried at that moment: only around 400 survived (Oliver-Smith 1986).

This event took place before the era of international post-earthquake reconnaissance missions, and as a result much less is known about it than for most of the other events we will look at.

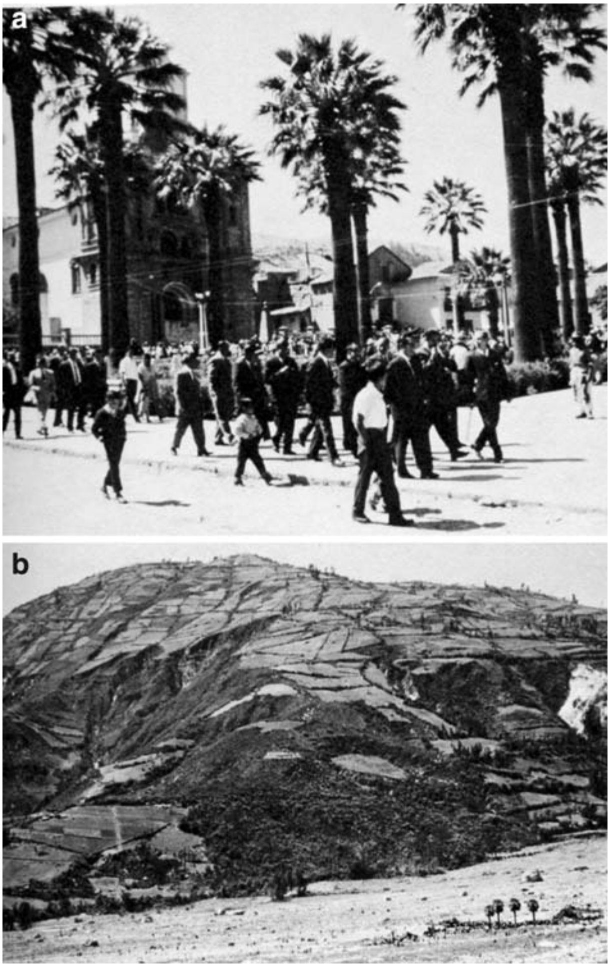


Fig. 10 The town of Yungay before (**a**) and after (**b**) the landslide. The tops of the tallest palm trees in the main plaza, visible at the right of (**b**) are virtually all, that is visible of Yungay afterwards (photos from Oliver-Smith 1986)

2.3.2 The 4.2.1976 Guatemala earthquake: Mw = 7.5; 23,000 deaths

This earthquake, which took place at 3.03 a.m. on 4 February 1976 was the result of a massive rupture of the long Motagua Fault, which forms the boundary between the Caribbean and North American plates. Fault rupture was observed over a distance of about 250 km, with slip averaging 1 m but reaching over 3 m in places, Fig. 11 (Bolt 1976). Intense ground shaking was felt over a very wide area, with buildings collapsing over an area of 9,000 km^2.

This is an area where there has been a long history of damaging earthquakes. The original capital, Antigua, to the west of Guatemala City, was destroyed in 1586, 1717, 1773 and again in 1874; and in 1917, 40% of the houses in Guatemala City had been destroyed; but before 1976, no building code had been enacted (indeed the form

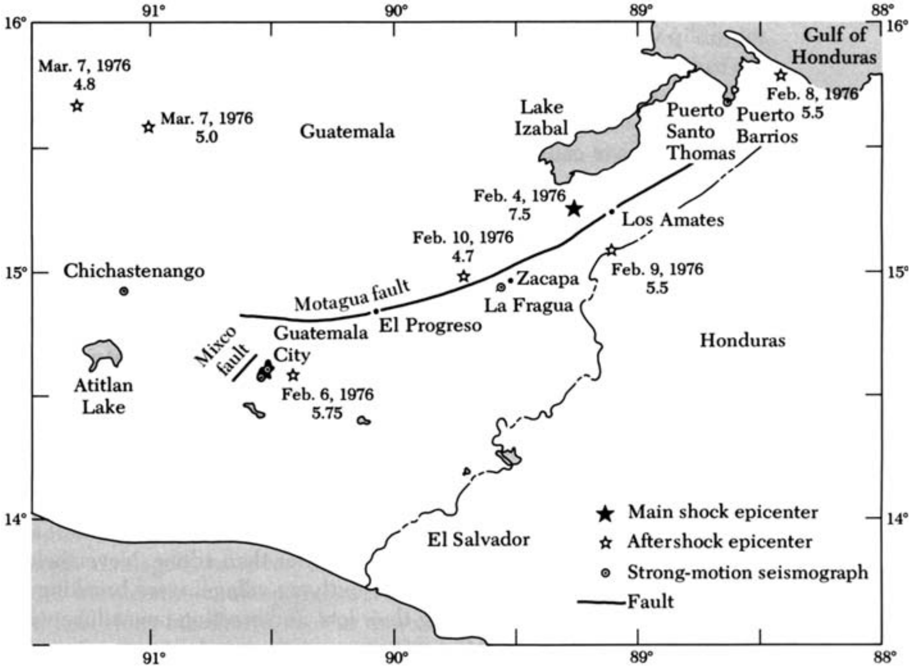


Fig. 11 The Motagua fault in Guatemala: location of the 4 February 1976 Mw = 7.5 earthquake (source: Bolt 1976)

of a specific national Guatemala building code was still under discussion during the author's visit there in 2003).

In the rural areas and small towns most affected by the intense ground shaking, in the Motagua River Valley, houses were generally single-storey, made with walls of adobe (sun-dried earth) blocks, and clay tiled roofs supported by timber rafters (Fig. 12). The walls had very little resistance to ground shaking, and failed, causing the heavy roofs to fall on the sleeping occupants. Although there are no casualty studies available, it can be assumed that most of those who died were crushed under falling masonry and roofs, with some succumbing to asphyxiation. According to Bolt the most common injuries among the survivors were "broken backs and smashed pelvises".

A better form of construction, bahareque—timber frames with an infill of lath and plaster—was reported to have withstood the shaking better than adobe. In and around Guatemala City, where the terrain is steeply incised by ravines, many landslides occurred, accentuating the damage and causing further casualties among the poorer families who occupied these areas of marginal land (and still do) (Figs. 13a, b). But vulnerable housing can be taken as the main cause of death.

2.3.3 The 28.7.1976 Tangshan Earthquake: Mw = 7.5; 242,000 deaths

This event was the most lethal disaster of modern times. The Mw = 7.5 earthquake which occurred at 3.42 a.m. local time on 28 July 1976 had its focus directly below Tangshan City, in Hebei Province of Northern China. Rupture occurred on a SW to

Fig. 12 Failure of adobe houses in the 1976 Guatemala earthquake (source: Cuny 1983)

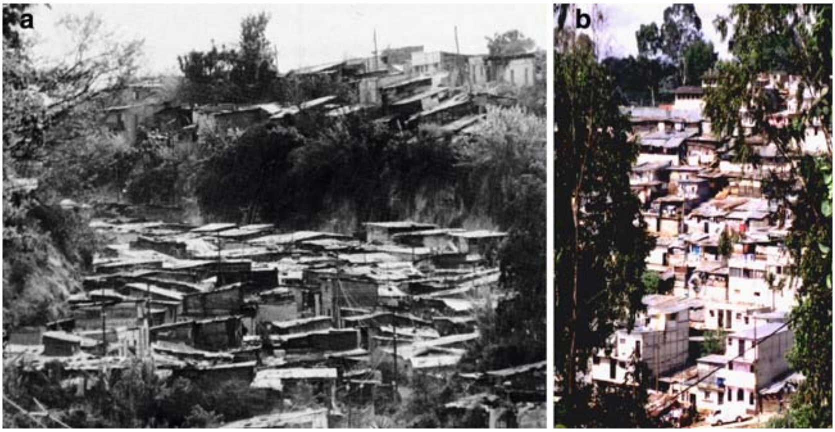


Fig. 13 Typical ravine housing in Guatemala City in 1970s (**a**) (Photo courtesy of Ian Davis), and in 2001 (**b**) (author's photo)

NE strike-slip fault system over a length of 100 km (Fig. 14), (Grossi et al. 2006); and surface faulting was observed over 10 km though downtown Tangshan with horizontal displacements up to 1.5 m. It was in this downtown area that the ground shaking was most intense, reaching XI on the Chinese Intensity Scale; but there was also major damage in Tianjin, 100 km to the southwest, and also in Beijing.

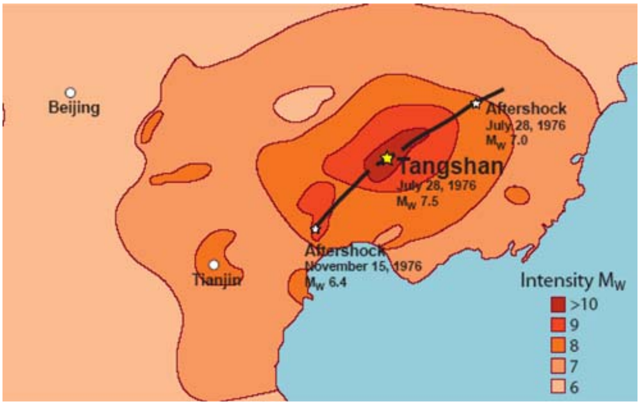


Fig. 14 The Tangshan earthquake of 28 September 1976. Isosseismal map (Courtesy of RMS)

Tangshan was an important industrial and mining city, with a population at the time of about 1.2 million people. Although a seismic zonation was in place in China at that time, Tangshan, where there was no historical record of a major earthquake, was only rated as at risk from intensity VI, at which level no special provision for earthquake resistance was required. Accordingly, most of the structures, both residential and industrial, were of unreinforced brick masonry with little lateral resistance, and no proper connection between walls, or between walls and roof (Housner and Duxin 2002). Within the zone of highest intensity, virtually all the brick residential structures collapsed, both single storey and multi-storey (Figs. 15, 16). Many industrial structures also collapsed. Destruction of buildings occurred over a very wide area, with total destruction of many villages, and major damage and loss of life extending to the larger city of Tianjin and even to Beijing. When the author visited the area in 1980, much damage and temporary housing was still visible (Fig. 17) (Spence 1981).

The official death toll from the earthquake was 242,000 (149,000 in Tangshan City itself), with a further 164,000 seriously injured, 3,800 disabled and 360,000 with other injuries. It has often been reported (USGS 2006; Housner and Duxin 2002) that the unofficial death toll was in fact much higher, even as high as 650,000. No detailed report on the casualties is available, but the recent RMS report (Grossi et al.) suggests that there are three primary reasons for the extraordinarily high death toll:

- First, the lack of earthquake-resistant design already noted, coupled with general construction deficiencies such as heavy roofs and lack of shear walls, causing many buildings to collapse, but also a lack of preparedness of the infrastructure.
- Second, the time of the earthquake; it took place at 3.42 a.m. local time, when most people would have been in bed, leading to a very high rate of entrapment (perhaps 80%).
- Third, the very high density of the urban population in the worst-affected areas, with buildings occupying up to 70% of the ground surface, and a population density reaching as high as 15,000 per km^2—this would have made rescue virtually impossible, offering little hope for those who survived the initial collapse.

Fig. 15 Aerial view of the totally devastated central part of Tangshan (source: China Academy of Building Research 1986)

Fig. 16 The huge death toll was mainly due to the total collapse of many brick masonry apartment buildings such as these (source: China Academy of Building Research 1986)

Fig. 17 Temporary housing in Tangshan at the time of author’s visit in 1980 (author’s photo)

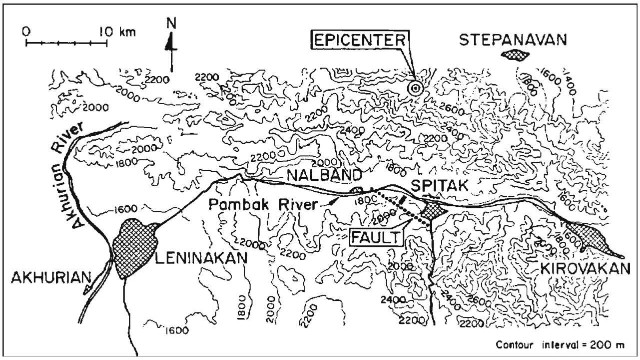


Fig. 18 Contour map showing the region of Armenia most affected by the earthquake of 7.12.1988 (Source: Wyllie and Filson 1989, Reproduced by permission of Earthquake Engineering Research Institute)

2.3.4 The 7.12.1988 Spitak, Armenia earthquake: Mw = 6.8; 25,000 deaths

This event took place on 7 December 1988. The main shock occurred at 11.41 a.m. close to the town of Spitak, between the larger towns of Leninakan and Kirovakan in what was then Soviet Armenia. The main shock was followed after 4 min by a major aftershock of $m_b = 5.9$ (Wyllie and Filson 1989). There was one strong motion record obtained which was located 27 km from the fault break: this registered peak ground accelerations of 0.18 g. The ground shaking from the main event lasted 30 s. The ground shaking intensity in the epicentral area (a region of about 15 × 3 km centred on Spitak), was MSK = X. A zone of intensity VIII-IX was mapped in Leninakan, 30 km from the epicentre (Fig. 18).

The combination of these two shocks caused huge damage. Spitak was a relatively recently built town, with many modern multi-storey apartment blocks. Some of these were of composite RC frame-stone buildings (up to five storeys), others were nine-storey precast concrete frame buildings or precast concrete panel buildings. In Spitak,

Fig. 19 Spitak earthquake of 7 December 1988. Nine-storey precast concrete frame buildings in Leninakan. The ones standing are severely damaged. Many collapsed completely (source: Wyllie and Filson 1989, Reproduced permission of Earthquake Engineering Research Institute)

87% of the structures collapsed or suffered such heavy damage that they had to be demolished. Even in Leninakan about 30% of the engineered structures suffered heavy damage, and 72 nine-storey precast concrete frame buildings (95% of the total) collapsed (Figs. 19, 20). Many died in these apartment blocks. In contrast, the pre-cast concrete panel buildings performed well, and not one of them collapsed (Bertero 1989).

Following this earthquake, an epidemiological study was carried out, following a particular cohort of over 32,000 randomly chosen individuals who were affected by the earthquake in Leninakan (now Gumri), the first time such a study had been carried out (Armenian et al. 1997). Data on age, location at the time of the earthquake, type of building and location in the building were collected from this cohort. These revealed a death rate of 2.5% in the population as a whole, of which 88% occurred during the first 24 h. Age was not a major influence over death rates, except for those above 60. However, those inside buildings were ten times more likely to be killed than those outside; while those in nine-storey buildings were over 40 times more likely to be killed than those in one-storey buildings. The likelihood of being killed was also significantly affected by location in the buildings, with those in upper floors at greatest risk. Thus, in this earthquake for the first time, something about the relationship between a building's type and its lethality to its occupants is revealed. The results are quite striking.

Fig. 20 Large-panel residential building in Leninakan which sustained only minor damage. These buildings generally performed very well, with only minor cracking at panel joints. According to Eisenberg (2006, Personal Communication), not a single building of this type has collapsed in an earthquake (source: Wyllie and Filson 1989, Reproduced by permission of Earthquake Engineering Research Institute)

2.3.5 The 21.6.1990 Manjil Earthquake: Mw = 7.7; 40,000 deaths

This earthquake, the first of two Iranian events in the list, occurred early in the morning on 21 June 1990 in the northern Iranian provinces of Gilan and Zanjan. It was relatively shallow and was associated with a WNW surface fault rupture, passing close to the town of Manjil. Strong ground shaking was felt over an area of about 600,000 km^2, including the cities of Tehran and Tabriz, though the immediate epicentral area was, fortunately, not very densely populated. Figure 21 shows the isoseismal map prepared by the Iranian Government. This map also indicates the location of previous events in this area, one of the most seismically active in the world: no less than 41 events with magnitude greater than 5 have been recorded within 200 km of the epicentre between 1900 and 1990 (UNDP 1990).

Building damage was immense over a wide area; around 95,000 houses (and of course many other buildings) were destroyed. Most buildings in this essentially rural area (whether in villages or small towns) were not engineered, and thus were not affected by the formal building regulations of Iran. There are two distinct styles of building according to the climate. In the area closest to the epicentre, around Manjil and Rudbar, an upland area with a harsh climate and large seasonal temperature variations, the traditional form of housing is single-storey load-bearing rubble-stone or adobe masonry, with flat mud roofs on timber joists; this type of construction suffered very high levels of damage, with a high proportion of structures collapsing (Fig. 22a). An entirely different form of construction is found on the more lowland areas of Gilan Province towards the Caspian Sea; here the climate is more temperate, and the traditional form of housing is two-storey timber frame, with a wattle and daub infill and comparatively lightweight roofing; although these areas also felt very strong

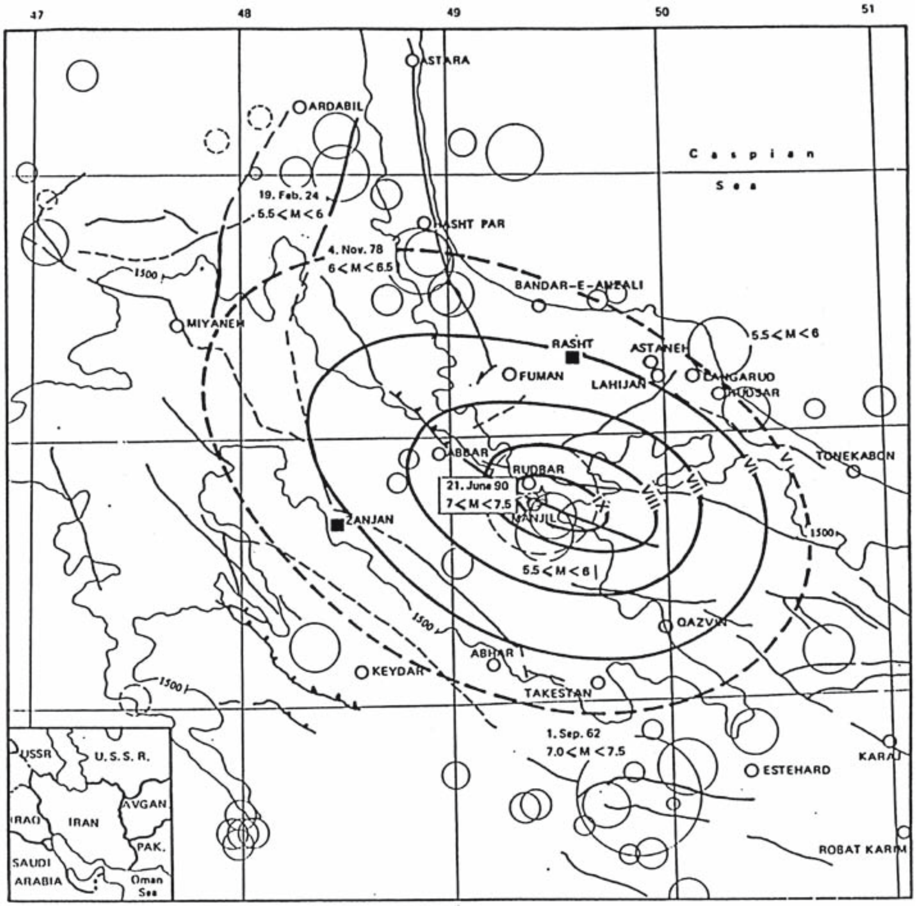


Fig. 21 Manjil Iran earthquake of 21 June 1990. The location and isoseismal map (source: UNDP 1990)

ground shaking very few of them were badly damaged in the earthquake (Fig. 22b). Many other forms of construction were found in the area, including multi-storey infilled reinforced concrete frames and infilled light steel frames (Fig. 23). The frames of these buildings tended to survive but their infill walls failed. Landslides and other land instabilities occurred, and added to ground shaking damage in some areas (UNDP 1990).

The large death toll of 40,000—in some villages 30% of the population was killed—is attributed by the UNDP team to the very high collapse rate of the traditional heavy masonry dwellings, as well as the time of day, when most would be asleep. People were trapped under heavy building materials and thick layers of dust and earth. Significantly, UNDP say that, in these epicentral villages "so many people were caught under the rubble that those who escaped the collapse were insufficient in number to pull out even the uninjured people many of whom suffocated under the blanket of dust". Nevertheless over the whole area it was estimated that 100,000 people were

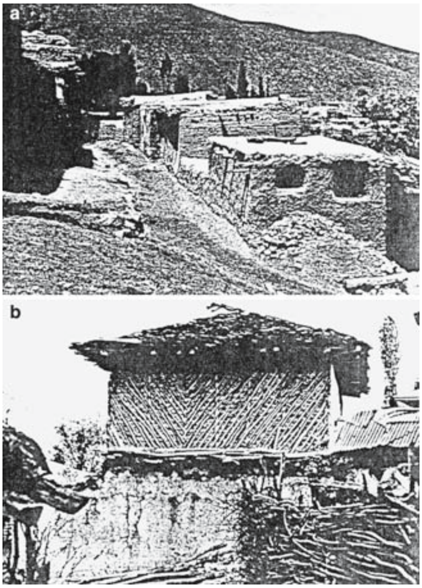


Fig. 22 (**a**) Typical adobe masonry dwellings of the mountain villages, and (**b**) timber frame construction of the Caspian Sea coast (source: UNDP 1990)

Fig. 23 The Manjil Iran earthquake of 21 June 1990. Failure of infilled steel frame building (source: EEFIT Image Database, Courtesy Earthquake Engineering Field Investigation Team (EEFIT) UK)

rescued from the rubble; and 36,000 were treated for injury (UNDP 1990; EEFIT 1991). There are many similarities with the later Bam event.

2.3.6 The 17.7.99 Kocaeli, Turkey earthquake: Mw = 7.6; 17,000 deaths

This earthquake was one of the most destructive ever to strike Turkey. It occurred at 3.02 a.m. local time, with its epicentre near Golcuk on the south coast of the Sea of Marmara; the magnitude was Mw = 7.6. A series of fault ruptures occurred on a section of the North Anatolian Fault (NAF) which extends under the sea west from Yalova and eastwards almost to Duzce, a distance of about 126 km. More than 10,000 km^2 of land area was strongly shaken by the event, an area which has been under rapid development for two decades, and in which 15 million people live, and 40% of Turkey's industry is located. An intensity map produced by the Turkish National Disaster Relief Centre is shown as Fig. 24. A subsequent (Mw = 7.1) earthquake took place on 12 November 1999 on an adjacent section of the North Anatolian Fault (NAF), near the town of Düzce, increasing the damage and causing a further 890 deaths. These 1999 events are the latest in a series of earthquakes on the NAF which have occurred since the 1939 Erzincan event (Fig. 25). The area has long been identified as one of the most seismically active in Turkey, and the Turkish Building Code gives it the highest loading requirements (Turkish Code 1975). In addition to ground shaking, many land instabilities took place, including a major coastal landslip near

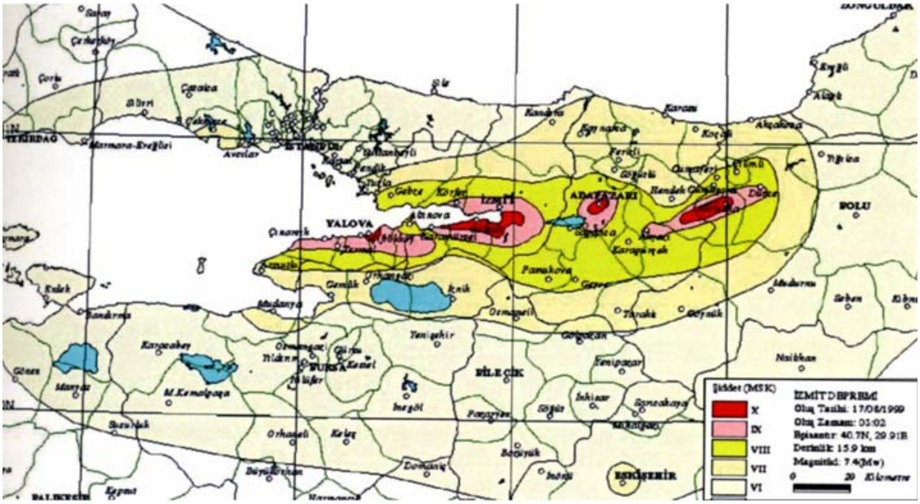


Fig. 24 Kocaeli earthquake of 17 July 1999: Isoseismal map produced by the Turkish National Disaster Relief Centre (source: Youd et al. 2000)

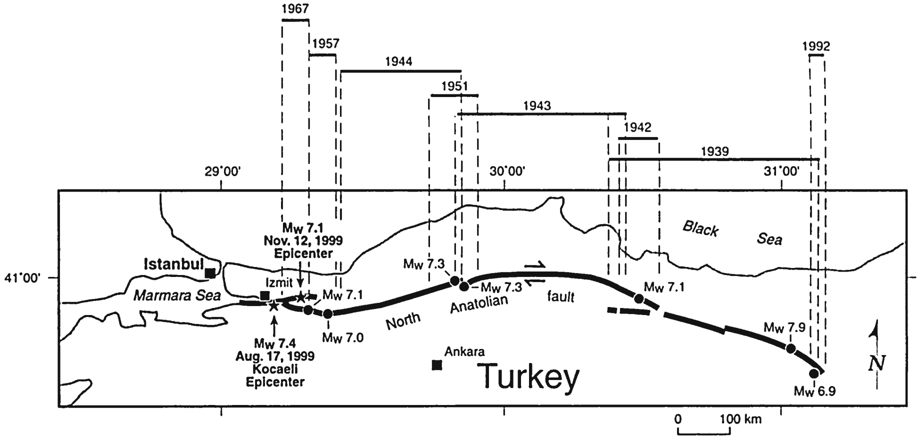


Fig. 25 The sequence of fault ruptures on the North Anatolian Fault since 1939 (source: Youd et al. 2000, Reproduced by permission of Earthquake Engineering Research Institute)

Degirmendere, and liquefaction also occurred in some urban areas, notably Adapazari; and many buildings were directly affected by the surface fault rupture (Youd et al. 2000).

During the rapid urbanisation of the Marmara Sea region, the predominant type of residential building is the multi-storey apartment block 4–7 storeys in height, made from a reinforced concrete frame with masonry infill (Fig. 26a). These coexist with many older two or three storey buildings, predominantly of masonry, the more recent of which have reinforced concrete floors and roofs, but some of which have timber floors and roof structures (Fig. 26b). A few old timber frame buildings still survive.

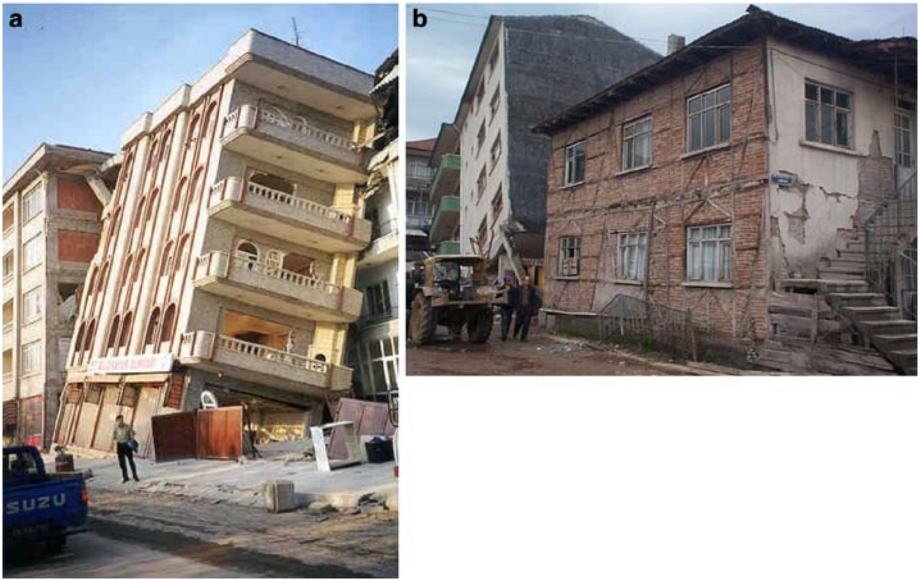


Fig. 26 Four to seven storey concrete frames buildings with infill masonry predominated in the main towns of the affected area (**a**). This one, in Adapazari, was destroyed by foundation failure. These are mixed with older masonry buildings of two or three storeys (**b**), some with timber floor and roof structures and sometimes timber lacing in the walls (Photos: (**a**) Matthew Free, (**b**) Dina D' Ayala reprinted courtesy of the Earthquake Engineering Field Investigation Team EEFIT, UK)

Modern steel frame and precast concrete construction systems are used for many industrial projects; and there are numerous historical structures in the area. At the time of day that the earthquake struck however, most people were at home, and the huge death toll was caused by the collapse of a very large number of multi-storey apartment buildings. According to Youd et al. (2000) an estimated 60,000–115,000 buildings collapsed or were damaged beyond repair, most of which were 5–7 storey apartment blocks built within the last 30 years. Detailed studies (D'Ayala and Free 2003) suggest that the most recent buildings (built since 1980) performed worse; and that there was a much higher collapse rate among buildings higher than four storeys compared with those of 1–3 storeys. The high failure rate of these apartment buildings has been attributed mainly to a failure to follow the code both in design and construction, and a failure of code enforcement through building control (Gülkan 2005).

Little overall analysis is available of the official totals of 17,439 killed and 43,954 injured. These are not differentiated by location or by the class of building in which they occurred. According to Youd et al. (2000) injuries were mostly "orthopaedic neurological, cuts scratches and bruising", but no breakdown is given. This makes the study carried by Petal at Bogazici University (Petal 2004) all the more important. She studied the experience of 453 families (representing 1861 individuals) in the hard hit town of Gölcük. Petal found that in Gölcük about 3.7% of the population were killed and 3.8% (almost the same number) hospitalised with injuries. The rate of all injuries was approximately 13.5% of the population, 47.2% minor, 45.2% moderate and 7.7% severe. Uniquely, the study also looks at the causes of the injury, and finds

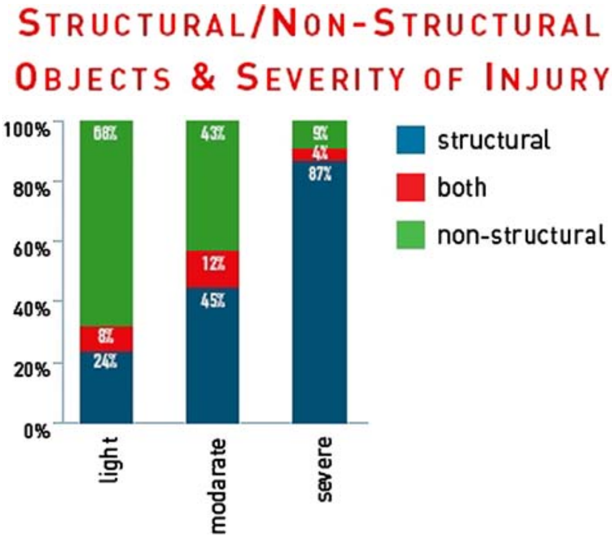


Fig. 27 Breakdown of injuries in the Kocaeli earthquake, by cause (structural or non-structural) (Courtesy of Marla Petal)

that while 91% of severe injuries have a structural cause, only 51% of moderate and 32% of light injuries have a wholly or partly structural origin (Fig. 27), indicating that non-structural hazards such as displaced partition walls, furniture and light-fittings can be responsible for many injuries.

2.3.7 The 26.1.2001 Bhuj Earthquake: Mw = 7.7, 14,000 deaths

On 26 January 2001, India's Republic Day, one of the most devastating earthquakes ever to strike India occurred in the Kachchh Region of Gujarat State. The earthquake's epicentre was located approximately 70 km east of the historic city of Bhuj. Heavy ground shaking affected an area of tens of thousands of km^2, but there was no surface fault rupture observed. The isoseismal map prepared by the EERI team is shown in Fig. 28 (Jain et al. 2002). The area has experienced a previous large earthquake (Mw about 8.0) in 1819, and a moderate one Mw = 7.0 in 1956, and is in the zone with the highest earthquake loading requirements in the Indian Code (ISI 1970).

Load-bearing masonry is the predominant way of building throughout the affected area, but methods have changed over time. The most common masonry technique is a single storey house with walls of random rubble masonry set in a mud mortar, with a clay tile roof: these buildings are found everywhere, both in the main towns and in the villages (Fig. 29a). More substantial dwellings use dressed or semi-dressed stone or sometimes clay brick walls; these are commonly two storey buildings: and in the last 30 years the use of reinforced concrete slabs for floors and roofs, with coursed masonry walls, has become common in the wealthier parts of Katchchh (Fig. 29b). The main towns now have also significant numbers of multi-storey apartment blocks in reinforced concrete (Fig. 29c). None of these forms of building were spared by

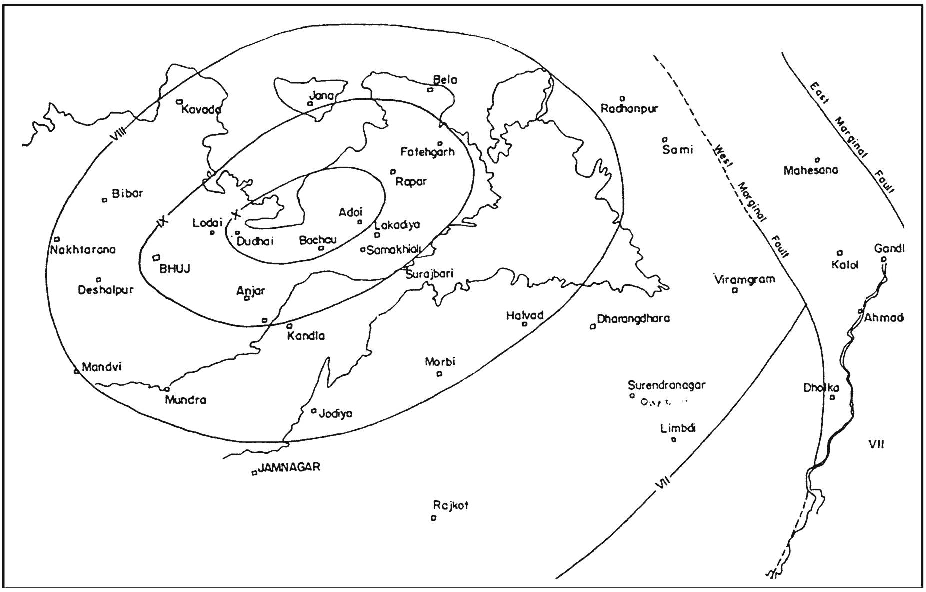


Fig. 28 The Bhuj earthquake of 26 January 2001. Isoseismal map prepared by the EERI team (source: Jain et al. 2002, Reproduced by permission of Earthquake Engineering Research Institute)

the intense widespread ground shaking on 26 January. The major city of Gandidham, and four large towns Bhuj, Anjar, Bhachau and Rapar, all in the Kachchh district, were devastated, as was every village within a wide area. Over 230,000 one and two storey masonry buildings and several hundred concrete frame buildings collapsed. In Ahmedabad, about 200 km from the epicentre, severe shaking was experienced and several dozens of multi-storey frame buildings collapsed. A survey of damaged buildings in Bhuj and neighbouring villages by EEFIT (Madabhushi and Haigh 2005) showed that the rubble masonry buildings performed worst (over 30% collapse rate) while masonry with RC slabs and RC frame apartment buildings performed better (7 and 3% collapse rates). The collapse of buildings in Ahmedabad, all of which were of multi-storey reinforced concrete frames, can be attributed to amplification of the ground motion through the deep alluvial deposits on which Ahmedabad stands, coupled with poor design and construction—soft-storey apartment blocks were common. The Indian Code is well-written and comprehensive, and dates from 1962 (ISI 1970). But it is not binding on private builders, and is largely ignored.

The toll of dead and injured shows that altogether 13,805 people were killed in the earthquake, 12,221 of them in the Katchchh District, but more than ten deaths were recorded in each of nine other districts, including 752 in Ahmedabad. There were 166,812 injured, 20,000 of them serious. The nature of injuries ranged from orthopaedic and head injuries to tissue losses, abdominal and thoracic trauma and amputations. Many children were killed, and there were more adult female than male deaths (Murty et al. 2005): but further information on types, causes and severity of injuries, and the numbers of hospitalised injuries, is not so far available. There can be little doubt, though, that failure of weak masonry walls and the failure and collapse

Fig. 29 Masonry and reinforced concrete building types in the Katchchh District (**a, b**) and typical damage patterns. Notice ground floor failure of the reinforced concrete building (**c**) (author's photos)

of dwellings, was the main cause of death, and the magnitude of the death toll is a reflection of the very wide area over which heavy ground shaking was observed, combined with the extreme weakness of the masonry buildings. Scarcity of water is a serious problem throughout Gujarat, and the widespread damage to water supply schemes exacerbated this problem, with unknown consequent health effects.

2.3.8 The 26.12.2003 Bam earthquake: Mw = 6.6; about 32,000 deaths

This earthquake, one of the most devastating in the history of Iran, occurred at 05.26 local time, on a hitherto unidentified fault passing under the historic city of Bam (Berberian 2005). Surface ruptures were identified along this fault south of Bam, and extending northwards toward the centre of the city. The area as a whole is one with a well-known history of active seismicity (nine earthquakes have been felt in Bam since the beginning of twentieth century); it has been said that Bam itself has not been hit by a major earthquake for over 2000 years (the lifetime of the ancient citadel), but this has been challenged (Berberian 2005). The earthquake was catastrophic in the city of Bam itself (far more than would be expected for an earthquake of moderate magnitude), as well as in the nearby town of Bharavat and neighbouring villages of Kerman Province. An intensity map is shown in Fig. 30, indicating shaking intensity

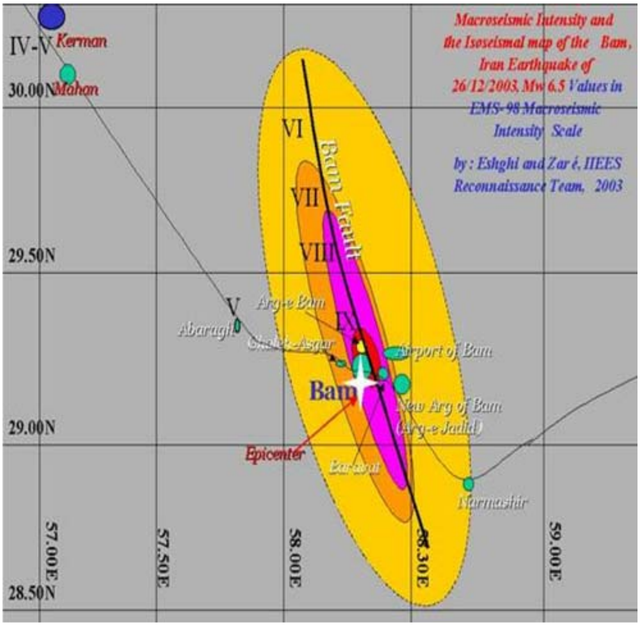


Fig. 30 Bam earthquake of 26 December 2003: isoseismal map (source IIEES 2003)

Fig. 31 High-resolution Satellite images of the centre of Bam before and after the earthquake showing the scale of damage (images: Courtesy of Digital Globe)

of MMI = VIII. However, a local accelerogram recorded a peak horizontal ground acceleration of 0.8 g, and a peak vertical ground acceleration of 1.0 g in Bam. This was one of the earliest earthquakes where the extent of the damage was clearly visible in satellite images (Fig. 31).

The massive death toll in Bam (around 20% of the total population of the area died) has been attributed to the extreme weakness of the adobe houses which are lived in by the majority of the population. This method of building has been documented in the World Housing Encyclopedia (Maheri et al. 2006) Figs. 32 and 33.

Fig. 32 Bam earthquake: collapse of typical adobe dwelling with vaulted roof (photo courtesy of Jubin Motamed)

Fig. 33 Failure of adobe structure in Bam earthquake (source: World Housing Encyclopedia, Reproduced by permission of Earthquake Engineering Research Institute)

It is derived from an appropriate response to the climate of Southern Iran, with high diurnal temperature swings, and also from the lack of timber for construction. But in the event of an earthquake its weakness is extreme. The problems include:

- Thick heavy walls, which attract large lateral seismic forces.
- Lack of connections between perpendicular walls.
- Heavy domed or vaulted mud roof, exerting lateral pressure on walls.
- Poor quality of adobe units (local sun-dried mud) as well as of mortar and bonding.

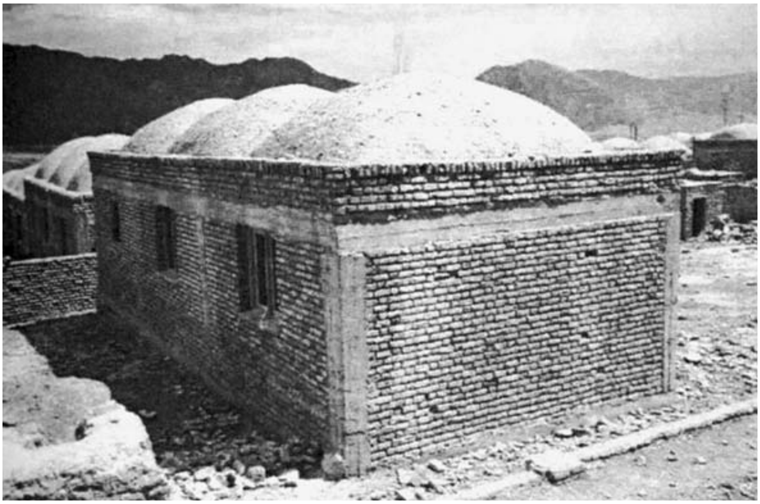


Fig. 34 Adobe construction with ring reinforced concrete ringbeam. These houses, built following the Gholbaf earthquake in Kerman Province in 1981, were again shaken by a powerful earthquake in 1998, but none suffered major damage (source: Maheri et al. 2006, Reproduced by permission of Earthquake Engineering Research Institute)

- Lack of foundations.
- Limited maintenance.

Many of these buildings simply disintegrated as a result of the ground shaking, leaving only heaps of dried mud brick rubble (Fig. 33). The danger to occupants is increased by their close spacing, leaving little opportunity for escape, and inhibiting search and rescue. However, it has been pointed out that these are not old buildings: many of them are recently built; only recently have attempts been made to develop a way of building dwellings which conforms to the climatic and space requirements, but which is able to resist earthquakes (Fig. 34).

The huge death toll of 31,828 (Ghafory-Ashtiany and Mousevi 2005) was undoubtedly the result of the collapse of very large numbers of dwellings, coupled with the time of day when most people were still at home. It has been said that only 2% of those who died were in buildings which did not collapse, so over 98% survived as long as the building did not collapse (Ghafory-Ashtiany and Mousevi 2005). Of a further 17,500 injuries, 9,477 were serious, and were treated in hospitals in Kerman and elsewhere as all the hospitals in Bam were severely damaged: abdominal trauma, pneumothorax, bladder rupture and head injuries constituted most emergency surgery cases. However, it has been suggested that a further very significant contribution to the death toll was the lack of immediate response capability (Movahedi 2005). The local emergency response was totally destroyed by the earthquake, and for the crucial first 24 hours the only rescue was being carried out by the local survivors using their bare hands. The loss of electricity and therefore light meant that rescue stopped at nightfall, and freezing temperatures reduced the chances of overnight survival under the rubble. Asphyxiation resulting from the huge amount of dust was suggested as a further cause of many deaths (Movahedi 2005).

2.3.9 The 26.12.04 Earthquake and Indian Ocean Tsunami; Mw = 9.3, 283,000 deaths

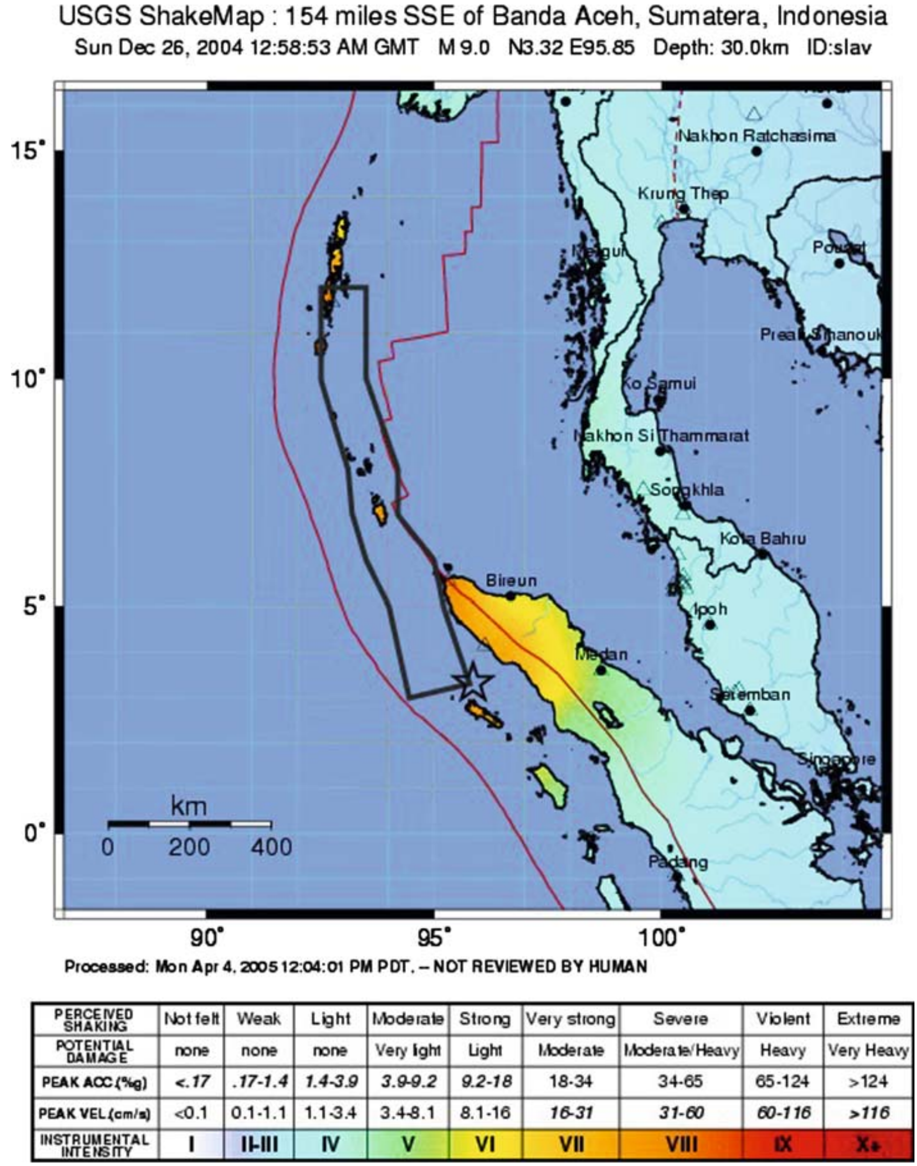
On 26 December 2004, one of the largest earthquakes of the last 100 years occurred in the Sunda trench off the Indonesian Coast, causing ground shaking over a wide region, and triggering a massive and destructive tsunami, which devastated the coasts bordering the Indian Ocean causing huge loss of life. The ground shaking was destructive throughout Aceh Province of Indonesia, particularly in the main city of Banda Aceh, and also in the Andaman and Nicobar Islands. But the tsunami carried the earthquake's energy over a much wider region, causing destruction throughout northern Sumatra, and in all the countries bordering the Indian Ocean, especially Thailand, Sri Lanka and India. Figure 35 shows the extent of ground shaking caused, in the form of MMI intensity assessments in the main towns. Figure 36 shows the ocean wave heights typically experienced; coastal run-up height varied widely along any coastline, depending on the shoreline configuration and bathymetry, but reached up to 20 m in parts of Sumatra, 5–8 m in Thailand, and 2–5 m in South-eastern India and Eastern and Southern Sri Lanka (Pomonis 2006).

The tsunami was devastating to small buildings wherever the run-up height was 2 m or more, and huge numbers of buildings of timber or traditional masonry were destroyed in Indonesia, Thailand and Sri Lanka (Pomonis 2006), Fig. 37a. Reinforced concrete buildings of several storeys often survived but with serious damage, although there were cases of collapse through scour under the foundations (Fig. 37b). Although the failure of these buildings certainly contributed to the level of casualties, unlike all the other earthquakes examined here, the huge loss of life was primarily due to the direct effects of the tsunami itself: victims were either drowned directly or as a result of injuries caused by impact with debris from buildings or other objects: "falling structures and waters full of swirling debris inflicted crush injuries, fractures and a variety of open and closed wounds" (WHO 2006). In Sri Lanka and Thailand, many of the victims were foreign tourists. It has been estimated (Pomonis 2006) that the death rate in the worst hit areas in Sri Lanka and Thailand was over 10% of the resident population within 1 km of the coast. It is clear from all accounts that an effective warning system, coupled with a better understanding among visitors of the phenomenon of tsunamis, could have saved many lives, since the tsunami struck the Thai and Sri Lankan coasts more than 90 min after the earthquake. Indeed 120 fishermen were killed by the tsunami in Somalia as much as 10 hours after its occurrence.

A study of the experiences of eyewitnesses conducted by Cambridge University (Spence et al. 2007), showed very pronounced correlation between survival and distance from the shore: all of those within 15 m of the shore reported serious injury or fatalities in their group, but less than half of those more than 30 m away did (Table 4). Most survivors who were in the affected zone attributed their survival either to prompt action in moving to safer ground, or to being in a building which survived.

2.3.10 The 8.10.05 Kashmir Earthquake: Mw = 7.6; 73,000 deaths

On 8 October 2005, at 08.50 a.m. local time an earthquake of magnitude Mw = 7.6 struck the Kashmir regions of Pakistan and India. The epicentre was located a little north of Muzaffarbad, the major town of Pakistan's AJK (Azad Jammu and Kashmir Province). It was located on the Jhelum Thrust (Taponnier 2006), part of the



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Fig. 35 Ground shaking intensity map of the ground shaking caused by the 26 December 2004 Indonesia earthquake (source:USGS: www.usgs.gov)

well-established thrust fault system associated with the subduction of the Indian plate below the Eurasian plate. Heavy ground shaking was felt over a very wide area, and was devastating for the nearby towns of Muzaffarabad, Balakot, Bagh and Rawalakot; but damage was severe in towns up to 50 km away, including Murree, Abbotabad and Mansehra in Pakistan, and Uri and Baramulla in India. In a much reported incident, an apartment block collapsed in Islamabad, 100 km away. (EERI 2005, 2006). A ground shaking intensity map is shown in Fig. 38. This was the most destructive event in the

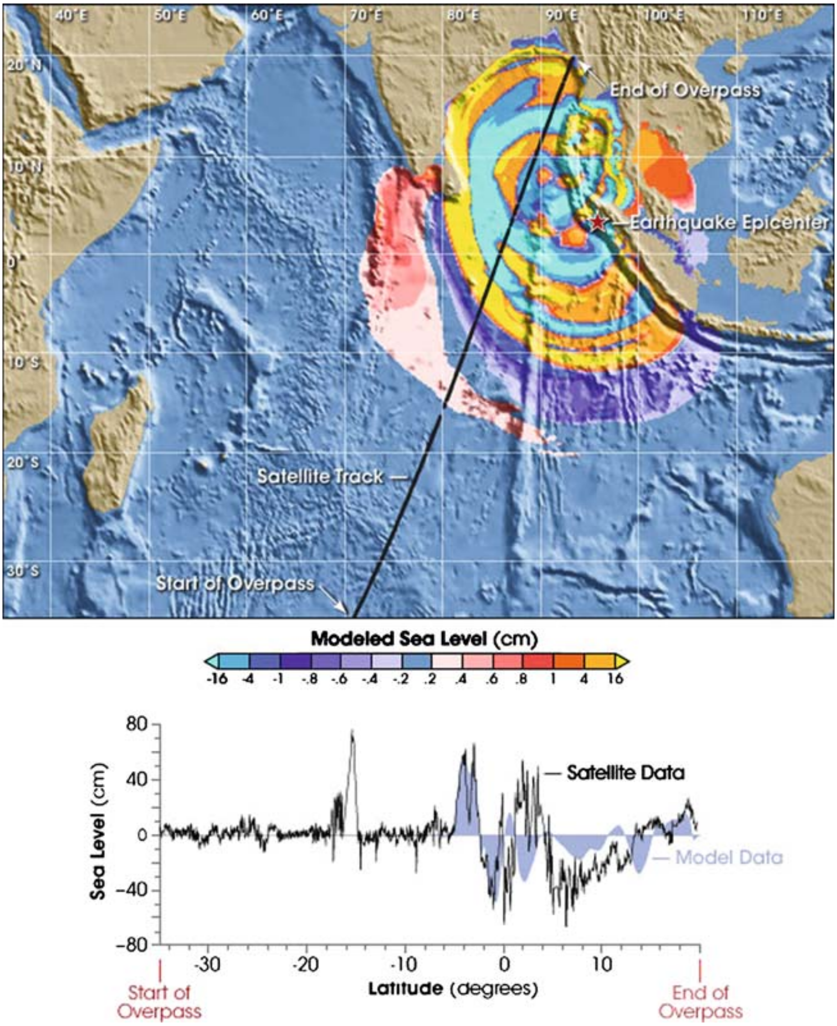


Fig. 36 Modelled ocean wave heights and satellite data from the 26 December 04 South Asian tsunami (source: NASA Earth Observatory, http://earthobservatory.nasa.gov/NaturalHazards)

Indian subcontinent in the last 50 years, causing as many as 73,000 deaths (maybe 20,000 of them children), 70,000 serious injuries, and over 2.5 million homeless. The death toll may well have been higher, as many missing were not counted as among the dead.

The high-death toll was undoubtedly primarily due to the widespread collapse of buildings in the area, most of them of masonry. Because of the harsh climate, buildings have traditionally been made from thick stone masonry, often using rounded riverbed stones in poor quality mud mortar, with thick mud roofs (Fig. 39a). In the past such walls were often tied together with timber lacings and the roof independently supported. However, timber is less and less used because of its scarcity and high value, and the severe ground shaking would have been more than enough to cause

Fig. 37 The 26 December 04 tsunami: typical building damage at Unawatuna, Sri Lanka where the tsunami run-up height was about 5 m in (**a**) masonry and (**b**) reinforced concrete structures (Courtesy of the Earthquake Engineering Field Investigation Team EEFIT, UK)

Table 4 Correlation of numbers of deaths and injuries with distance from shore in eyewitness reports of the 26 December 2004 South Asian Tsunami (source: Spence et al. 2007)

Distance from shore (m)	Proportion reporting either fatality or injury (%)
Less than 15	100
15–30	33
30–60	50
60–150	46
150–500	54
More than 500	33

Fig. 38 Isoseismal map of the 8 October 05 Kashmir earthquake (source: www.asc-India.org)

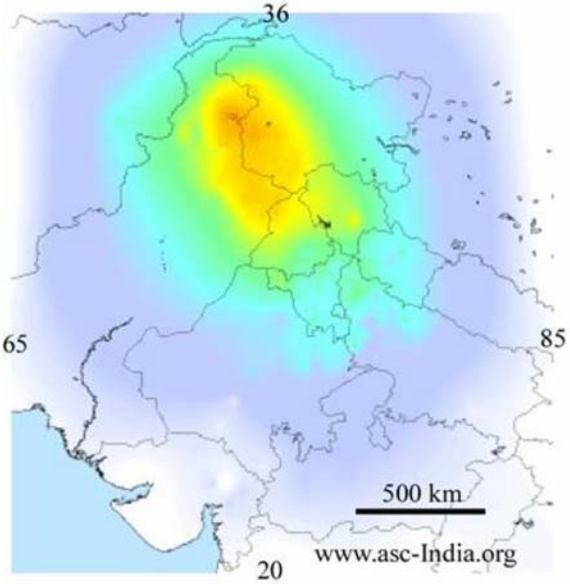


Fig. 39 Traditional masonry construction (**a**), and damage to reinforced concrete construction (**b**), Kashmir earthquake (Photos courtesy of Emily So (**a**) and author (**b**)

roof collapse. In many places more modern building types using concrete blocks and reinforced concrete frames also collapsed (Fig. 39b), and this included many government-built schools and barracks; again evidence shows poor quality building standards. But a factor which certainly also contributed to the high-death toll was the inaccessibility of much of the affected area, as a result of the numerous landslides triggered by the earthquake; aid was thus very slow to arrive, and many of the survivors had to walk long distances in difficult terrain to reach a functioning health centre; this also complicated injuries bringing on infections and resulting in more drastic medical measures. Many more with head and chest injuries from falling masonry did not survive until medical help arrived. And search and rescue capability in the crucial early stages was concentrated in Islamabad, where few buildings failed, rather than being sent to the epicentral area.

Working with the University of Peshawar, Cambridge University has set up a programme of survivor interviews, in order to determine more precisely the relationship between casualties and injuries, location and access to treatment, and the type of building the survivors were in at the time of the event. The results of the first pilot study of 40 families indicated that 72% of their houses were destroyed, and that 86% of injuries were caused by the structural failure. A distribution of the injuries by severity and the affected body region is shown in Fig. 40 (So 2006). Of 148 reported injuries, 12 were amputations. A further 400 interviews were completed and are currently (8 November 2006) being analysed.

2.4 Conclusions from the overview of the most lethal earthquakes

What then can we conclude from this very brief survey of the most lethal earthquakes of the half-century just past? The first and most obvious point is that there is no single event among those listed which occurred in a high-income country. Indeed there is no event from such a country even close in lethality to these top ten killers. If we look at the USGS list of the most lethal earthquakes since since 1960 (those causing more than 1,000 deaths) only the events of Kobe (1995), with 5,500 deaths, Irpinia (1980) with 3,000 deaths and Friuli (1976), with 1,000 deaths, occurred in the industrialised world, a total of less than 10,000 of the 800,000 deaths which have occurred during that time. It could be argued that this demonstrates that earthquake mortality has to be seen primarily as a developmental issue (Cuny 1983).

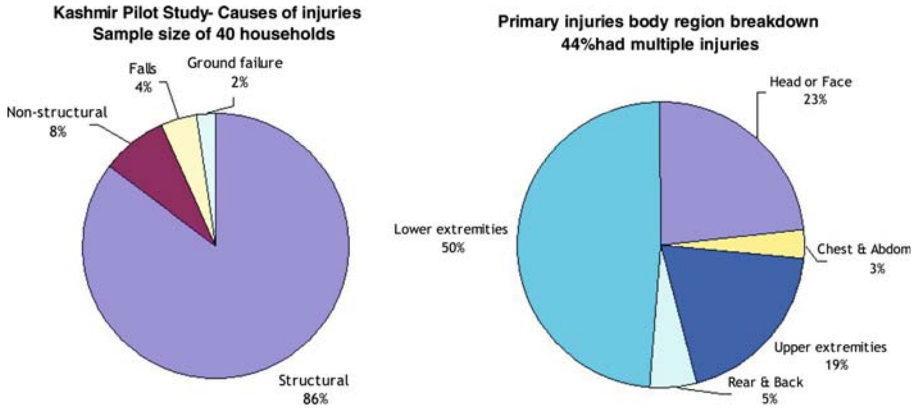


Fig. 40 Data on causes and types of injuries from pilot study of survivors of Kashmir earthquake (source: So 2006)

Table 5 The ten most lethal earthquakes: summary of known causes of death and injury

Event	Date	Principal collapsed building types	Principal causes of deaths	Principal secondary hazards reported
Ancash	31/05/1970	Adobe masonry residential buildings	Building collapse	Flooding, avalanche
Guatemala	04/02/1976	Adobe masonry residential buildings	Building collapse	Landslides
Tangshan	28/07/1976	Brick masonry residential and industrial buildings	Building collapse	City lies on unstable alluvial soil
Armenia	07/12/1988	Multi-storey apartments, masonry and rc frame	Building collapse	
Manjil	21/06/1990	Earthen and stone masonry	Building collapse	Lanslides
Kocaeli	17/08/1999	Reinforced concrete frame	Building collapse	Ground failures
Bhuj	26/01/2001	Rubble masonry and rc frame	Building collapse	
Bam	26/12/2003	Adobe masonry residential buildings with earth vaults	Building collapse	
Indian Ocean	26/12/2004	Timber and masonry small residential buildings	Drowning and structural failure	Tsunami
Kashmir	08/10/2006	Concrete block and stone masonry, reinforced concrete frame	Building collapse	Landslides, ground instability

Second, there is also no doubt that the major cause of death is building collapse. Unreinforced masonry buildings remain perhaps the greatest danger to their inhabitants, and the weaker the masonry, the higher the death toll in the event of a strong earthquake, as evidenced by the high loss of life in the moderate sized Bam (2004) earthquake, and the huge spread of building collapse in Kashmir (2005). Lack of timber or other materials to introduce some capacity to resist tension is an important part of the problem, and will grow more serious as population growth accelerates deforestation. However recent earthquakes (Spitak 1998; Kocaeli, 1999) demonstrate that there are also huge dangers from reinforced concrete buildings when built without codes, or proper consideration of potential earthquake loading. These earthquakes are a warning for the many earthquake-risk cities (Guatemala City, Kathmandu, Lima and Tehran) whose population is growing rapidly without adequate building control (Coburn and Spence 2002), and we can, on current trends, expect to see more numerous reinforced concrete failures in the future. But even though the weakness of buildings under ground shaking is greatest cause of death, tsunami and landslide risk are not to be ignored, as the Peru earthquake of 1970 and the 2004 Indian Ocean tsunami demonstrate.

Data on the precise causes of death and injury is in most cases not available, or only from relatively small samples. Some of the evidence is summarised in Table 5. It seems evident that most of the deaths are the result of injuries sustained when buildings collapse and their roofs or walls fall on the occupants. In some earthquakes, there is evidence that asphyxiation resulting from the dust and fine material released when buildings collapse has contributed. And in several earthquakes lack of timely rescue and treatment of wounds has increased the death toll. Severe injuries also result, often in smaller numbers than deaths; these are also the result of complete building collapses, but may also occur even when the building damage level is moderate, through the displacement of the building contents. Critical injuries, involving limb amputations or spinal injuries leading to permanent disablement, are comparatively small in number compared with the death toll.

So how could death tolls have been reduced? Better building standards is the obvious answer, but for a variety of reasons which will be explored in Part 2, these are very difficult to achieve in communities in which the daily struggle for survival leaves little time or energy for planning for longer-term risks.

What about the relocation of communities away from high-hazard locations, or at least discouraging building there? In most cases, this is not really an option. In many of the most lethal events, the ground shaking hazard was not well-known. And even where it was, the area potentially at risk was too large, and government control too weak to contemplate such a major population shift to be considered. Even where the risk is well-established because an event has occurred, the population are usually reluctant to leave their land and perhaps livelihood as a measure to counter the earthquake threat. The tsunami risk could of course be reduced by moving communities away from the coast, but this too has been difficult to impose on fishing communities in Sri Lanka.

An ability to predict earthquakes would of course be able to save many lives through timely evacuation; and this was famously achieved in the Haicheng earthquake in China in 1975. However, many doubt whether the methods used in this case have any scientific validity; and at present the prevailing view is we are not close to developing any useable system for earthquake prediction, and that the goal may be unattainable (Geller 1997).

Improvement of emergency services, and their protection, could in many cases have saved lives, possibly many. Several of the accounts given show that search and rescue was slow to arrive, and was disrupted by the failure in the earthquake of the buildings and infrastructure on which the emergency services relied.

But we must set improvement in building standards, particularly in housing, as the principal objective to be achieved if, in the future, as large or larger death tolls as those of the recent past are to be avoided. Section 4 will look at some possible ways to achieve this. But before this, Section 3, will examine how much progress has been made towards this goal in a number of the at-risk countries.

3 Successes and failures: a country comparison

3.1 Introduction: the survey

This section aims to examine, country by country, across the world, what has and has not been achieved in reducing earthquake risks over the last 50 years, how this was achieved, and what remains to be done. No recent global survey of this kind seems to exist, so it was decided to try to enlist the help of some of each country's most experienced and best-informed experts. For this kind of survey, a long formal questionnaire was not thought appropriate, so it was done by means of an email, containing just four questions (Box 2.1 below). The questions asked what the respondents saw as the successes and failures in earthquake protection in their particular country or region over the last 50 years; how effective the implementation of new codes of practice have been (practically all countries have advanced their codes considerably and several times over the period); what proportion of unsafe buildings they thought still remained in the country's building stock; and whether there were programmes in place to assess and upgrade unsafe buildings. Any available supporting papers were also requested. Many other questions could have been asked, but it was hoped that by keeping the questions short, at least some replies would be received.

Box 2.1 The questionnaire

1. In your view what have been the most significant successes and failures of earthquake protection in your country during the past 50 years?
2. How successful has been the implementation of new codes of practice in the design and construction of new buildings? What have been the major obstacles?
3. What do you estimate is the proportion of unsafe buildings (i.e. built before current codes, or without applying codes) in the current building stock?
4. Are there any programmes in place or in development to assess and upgrade unsafe buildings (public buildings—e.g. schools and hospitals; residential buildings?) and how successful have these programmes been?

During the summer of 2006, this questionnaire was sent to 45 different experts in 27 different countries. The response was remarkable: from this group, no less than 31 replies were received, and these covered the situation in 22 of the 27 countries approached. All replies addressed the four questions and some of the replies were detailed and extensive. The author is deeply indebted for the assistance that these individuals (whose names are acknowledged below) have provided in carrying out this survey. On the basis of the replies, I have constructed Tables 6–9, which summarise the responses country by country, for all the countries from which responses were received. In the USA, the responses were separated by region, California and Eastern North America being distinguished.

Table 6 Successes and failures country table: success stories

Country	Successes	Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
California	Licensing of engineers and geologists Field and Riley Acts (1933) Hospital Seismic Safety Act Assessment and upgrading of dams Hazard mapping and microzonation (Alquist-Priolo Act, 1972) California Seismic Safety Commission Unreinforced Masonry Act (1985) Standardised Emergency Management System (mid 1990s) Upgrading of Government and university buildings Retrofit of highways Improved codes recognising ductility NEHRP and research funding Earthquake reconnaissance Market-driven building upgrading by private owners	Remaining unsafe public school buildings Remaining non-ductile RC buildings Lack of action on Zone3 areas Failure to identify steel frame problems pre-Northridge Failure to identify highway problems pre-1990 Collapse of FEMA	Generally good, SEAOC Blue Book is standard. Healthy code development But lack of good professionals for checking	Unsafe: 5% remaining non-ductile RC and URM buildings Below current code: 60% housing, 50% commercial, 30% public buildings	URM buildings Existing hospitals Public Schools (Field Act) Residential (some communities) Universities	Tom Tobin Charles Scawthorn Mary Comerio

Table 6 continued

Country	Successes	Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Development of insurance Methods for assessment and retrofit					
Eastern North America	Accomplishments of NEHRP namely: National Eq hazards maps (USGS) Seismic design provisions for new buildings (FEMA) adopted in International Building Code affecting $ bns of new construction Guidelines for rehabilitation of existing buildings and bridges (FEMA and FHWA) Adoption of seismic provisions in local building codes for Boston (1970s) New York City (1990s), Charleston SC and other major cities.	Lack of regulations to address risk of pre-code buildings Slowness of adoption of regulations due to fear of increased costs	Thought to be good	Most construction in major cities pre-dates current codes.	FEMA Technical Manuals available to provide decision support. But upgrading of pre-code buildings is voluntary and is very limited in ENA	Tom O’ Rourke Fred Krimgold

Table 6 continued

Country	Successes	Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Application of ATC-20, post earthquake inspection protocol for damage assessment after 9/11 WTC attack					
Japan	Enactment of first nationwide building code in 1920 Enactment of building standards Law in 1950 Improvement of design code introducing ductility requirement in 1981 Progressive improvement in earthquake-resistance of wooden dwellings Progressive decline in death rates from major earthquakes Development of dense seismograph network Development of earthquake catalogue and probabilistic hazards map	Remaining at-risk existing buildings, particularly houses Corruption in approval of many post-1981 rc structures Failure to identify Kobe as a high-risk area Lack of adequate earthquake insurance Inadequate water supplies for emergency	Generally good apart from scandal noted. Japan's codes the only major alternative to UBC	Wooden houses: large numbers perhaps 50% built before 1981 awaiting retrofit. Also 23,000 RC apartment buildings Below current code: more than 25% of housing; 60% of commercial and 50% of public buildings	Public schools since Kobe Some other buildings, but slow progress	Yutaka Ohta Charles Scawthorn

Table 6 continued

Country	Successes	Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Tokai special countermeasures Zone Significant retrofitting of public infrastructure Real-time response to earthquakes					
New Zealand	Pioneering research into behaviour of RC structures-Park and Paulay and development of capacity design principles Invention and first application of base isolation Development of a national earthquake insurance scheme (EQC) Development of national codes and standards High level of technical skills Improvement of earthquake-resistance of built environment over time	Low level of official funding of code development Decline in technical development and training of design engineers and building officials Lack of progress in retrofitting pre-1976 brittle RC structures Lack of earthquake regulations for most equipment and plant Lack of hospital capacity to deal with a large earthquake	Generally successful; but recent codes are too large and complex	50% (and 58% of commercial and industrial buildings) built pre 1976; 5–10% would not perform well in design earthquake	Extensive retrofitting of URM buildings since 1968 Retrofitting of brittle rc structures starting in 2004 Schools assessed and upgraded in 1990s	David Dowrick David Hopkins Andrew Charleson

Table 6 continued

Country	Successes	Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Successful retrofit programmes and appropriate standards Improved understanding of NZ seismicity International collaborations					

Table 7 Successes and failures country table: Europe

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
Greece	Despite regular earthquakes, low death tolls throughout last 50 years High earthquake risk awareness among population, leading to demand for earthquake-resistant construction Rapid response to global trends in updating codes in 1959, 1984, 1995, 2000, 2004 Improvement in standards of construction Establishment of specialised research institutions and OASP	Poor quality rc construction pre 1984 Poor land-use planning and control of urban development continues Training of workforce and on-site supervision inadequate Limited government funding for risk mitigation Limited and fragmented observation network	Good, especially since 1984: less good in 1960–1984 About 20–25% of buildings erected without permission Subsequent building alterations have resulted in collapses	No estimate available: 30% are pre-1961, but not necessarily unsafe: some post-1961 buildings may be unsafe	Assessment required for all publicly owned schools First level evaluation (visual screening) done on 2,500 (about 12%) of all school buildings; and second level evaluation done for 500 in Athens region	Panayotis Carydis Antonios Pomonis

Table 7 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
Italy	1909 First seismic code and first seismic zonation in South Italy after the Messina earthquake 1980 First seismic zonation in the whole Italy based on PSHA 1974, 1986, 1996 and 2003 Upgrade of seismic zonation and seismic code 1980-1984-1997-1998-2002 Repair and upgrading of damaged buildings by earthquakes funded by central government and Regions	1998 Proposal for a new seismic zonation and a new seismic code not put in force 2003–2006 Too much time needed to implement the national plan for school retrofit and the national plan for seismic assessment of strategic buildings. Regions were not ready for prioritizing buildings. 1997–2005 Incentives—i.e. tax reductions -for private building upgrading were not enough Modern codes implemented too late to apply to most of the buildings	Implementation of 2003 code difficult, due to postponements in enforcing the new code, even now not required. Lack of software immediately available. New concepts difficult to understand.	Almost 100% of masonry buildings More than 60% of the RC buildings	2003 National Plan for assessing hospitals, schools, bridges, churches, etc. National plan for the upgrade or retrofit of schools Upgrading and retrofitting of damaged buildings by earthquakes. Several Regional plans for the upgrade of undamaged residential buildings, e.g. Sicily	Agostino Goretti Giulio Zuccaro Mauro Dolce

Table 7 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	2003–2006 National plan for the seismic assessment of strategic and relevant buildings 2004–2006 National plan for school seismic upgrade/retrofit	Resources available for upgrading the existing building stock inadequate			Funds are limited and difficulty in prioritisation	
Romania	1963 Regulations for earthquake resistant design introduced Regulations updated in 1970, 1978, 1981, 1992, 1996 in line with international norms High quality of education of engineers in post-war period Well-established design institutes (until 1989) Very limited number of failures of buildings designed to code in 1977 eq	Many buildings with cumulative damage caused by 1977 earthquake still not strengthened Pressures of market economy since 1989 have lowered standards of education and design	Fairly successful, in codes used to the present; but difficulties expected in adapting to new Eurocode-consistent code	No estimate available. But most urban buildings are built post 1963 and to code. Rural buildings have an intrinsic earthquake resistance	Yes. Numerous schools have been evaluated, hundreds strengthened. Several important hospitals strengthened. There is a programme to strengthen the 100 highest-risk residential buildings in Bucharest, but so far only 10% done	Horea Sandi

Table 7 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
Slovenia	Successful implementation of codes High knowledge of earthquake engineering among structural engineers	Late (1963) adoption of first seismic code Many pre-1963 post-war structures some of which are unsafe Lack of a programme to strengthen or remove them	No problems with implementation of previous (1963 and 1981 codes) Greater problems expected with EC8	73% of all buildings are URM, but not all vulnerable In event of 400-year earthquake, 20% of precode and 3% of old code buildings may collapse or partially collapse	No comprehensive programme. Rapid assessment of school buildings completed, and some strengthening funded. Law requiring assessment and upgrading of of important buildings adopted, but not implemented	Peter Fajfar
Russia	Introduction of standard response spectra in State Seismic Code of 1957, ahead of other countries. Development of prefabricated rc panel housing systems shown to be effective in subsequent earthquakes.	Poor state support for earthquake engineering Very limited interaction with international research	In former USSR, effective state system for checking code compliance existed; but design organisation less good since democratic reforms. Poor quality of construction especially in large-scale building construction.	Typically 60–80% of ordinary housing below current code requirements	Russian Federal Programme for Seismic Disaster Mitigation is in operation since 2002. Many buildings evealuated and some strengthened. But programme has little financial support, and inadequate research to define prioritisation	Jacob Eisenberg

Table 7 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Pioneering development and wide application of semi-isolated buildings and bridges. Building of 100 ton shaking tables in 1960s. Novel approach to seismic zonation.					
France	Enforcement of seismic loading since 1987—ordinary buildings since 1991. AFPS work to develop recommendations	Poor quality control in construction	Successful thanks to AFPS guidelines and training But some difficulty communicating to small design offices	No estimate available Most construction is below current code but not necessarily unsafe	No general programmes. But law requires upgrading of public buildings to be to current seismic code, and some upgrading done Newly initiated National Seismic Prevention Plan will deal with assessment and retrofit of important buildings	Alain Pecker
Spain	Application of seismic code since 1968, with updates in 1974, 1992 and 2002	Widespread use of flat slab construction	Code applied in loading, but not structural detailing	In Barcelona, about 70% of existing buildings are pre-code, and have high seismic vulnerability	No programmes. Project by National Civil Protection to identify most vulnerable high importance buildings in the country	Alex Barbat

Table 7 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Urban risk evaluations for important cities by Civil Protection	Lack of project control with respect to seismic design Lack of seismic protection culture among professionls	Difficulty for designers to understand concepts			
Austria	Seismic code is in place for the 20% of the country with some seimic risk and is close to EC8.	Low awareness of seismic risk amongst professionals	Code application is good, except for upgrading of old masonry buildings. Workshops for EC8 guidance in progress	60–80% of all construction in the seismic areas are below code	Some hospital buildings assessed. A general assessment of schools and hospitals beginning soon in Vienna, and will later spread to whole seismic area	Rainer Flesch
Portugal	Participation in modernizing codes, leading to EC8 Development of high level of research and academic expertise, and good standard of professional education	Apart from Azores, no national programme of risk mitigation adopted at national level. Lack of scientific/professional consensus of the level of risk.	Application of 1983 code is mainly OK, but implementation in some small offices not adequate. Quality control in large projects good, but not good in smaller ones.	In earthquake areas, 22–25% of buildings are masonry built pre 1930 with high vulnerability. Plus 30–35% of buildings are RC pre 1980, with poor seismic resistance and poor detailing	In Azores since 1998, strengthening is integrated with post-earthquake repair, even for low-cost housing. In continental Portugal, some studies on schools and hospitals done, but no programme exists for upgrading	Carlos Oliveira

Table 7 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Some improvement in standard of construction Increased public awareness Development (by SPES) of a proposed 20-year national programme for earthquake risk mitigation	Poor communication between scientific and earthquake engineering communities No manual for retrofitting vulnerable structures.	Concern that EC8 will be difficult to implement, because of its complexity for designers.			

Table 8 Successes and failured country table: movers

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
Colombia	National seismic code introduced in 1984, updated 1997 Inclusion of section on design and construction of small buildings Research studies on adobe and bamboo structures, and publication of guidelines for these buildings Manual for non-professionals on RC construction Microzonation and seismic risk studies for separate cities	Poor building control, especially in non-formal construction Large remaining potential for disaster (Disaster Deficit Index)	Qualified engineers understand and apply the code, but no application in informal construction	Estimated 80% of Bogota buildings are unsafe, or below code standard	Studies done for retrofitting of public buildings, and some completed, but little so far done in proportion to size of problem due to lack of funds	Omar Cardona

Table 8 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
Caribbean	Greater awareness of the need to consider earthquakes in designing buildings esp in Trinidad and Tobago, Puerto Rico, Dominican Republic and Jamaica. Earthquake-resistant design requirements are now incorporated in most of the national building standards in the Caribbean region. The number of engineers competent to design earthquake-resistant structures is increasing. Two base-isolated buildings (schools) have been constructed in Martinique and others under consideration.	Some islands do not acknowledge the earthquake hazard. Design standards often ignored. Engineers do not consider earthquakes in their designs. Ductile detailing requirements are usually ignored. Architects actively resist engineers efforts to promote earthquake-resistant design concept. Electrical and mechanical engineers largely ignore earthquakes.	As indicated, only partially successful. Unnecessary proliferation of standards documents so designers pick and choose. Regulatory authorities ill-equipped to check earthquake-resistant designs leading to inadequate enforcement of standards. Little (or no) attention to the training of practitioners in use of standards.	Most pre-1960 buildings have no specific earthquake-resistant design. Even now, most buildings are designed without taking into account available earthquake-resistant design standards. Pre-code buildings are not necessarily unsafe: many of them would be safe even though not consciously designed to be so.	PAHO (the regional office of WHO) has been active in promoting safe hospitals, vulnerability assessments of existing health-care facilities, support to governments for retrofitting health-care facilities, organising training courses etc. In spite of the efforts of PED-PAHO over the past two decades, progress "on the ground" has been slow	Tony Gibbs

Table 8 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Some strong-motion accelerographs have been installed and some results are available.	Earthquake-resistant design for infrastructural projects is rare. Earthquake-resistant design principles are poorly taught at universities and colleges.				
Turkey	Good code, well-understood and applied by many engineers, updated with new hazard map in 1998 Comprehensive legislative approach at national level for disaster management	Enormous loss of life in earthquakes—14,800 in 1999, and nearly 100,000 over twentieth century. Large vulnerability of most of the residential building stock through rapid population growth, lack of engineered design, and lack of code enforcement,	Poor. Design by small private firms, not properly checked by municipality. No proper oversight of work on site. No penalties for faulty construction	Given strong earthquake, maybe 10% of 3-4 storey RC buildings may collapse, and irreparable damage to up to 30%	Yes. A number of schemes and funding sources, mostly in Istanbul and Marmara Sea Region. ISM-EP (World Bank funding) will fund retrofitting of 50 hospitals and many school buildings in Istanbul	Polat Gülkan

Table 8 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Many significant new initiatives following the 1999 earthquake Awareness of risk to major cities (eg Istanbul) has triggered risk studies and retrofitting projects Establishment of DASK—national earthquake insurance scheme Responsibilities of local authorities have been expanded into disaster mitigation Internationally leading research on earthquake engineering and disaster management Excellent international collaborations	Failure to pass into Law many important decrees issued following Kocaeli earthquake Inadequate penalties for faulty construction Disaster management system is top–down and does not encourage active community participation Lack of rewards in DASK for mitigation measures. Inadequate financial support for mitigation measures Lack of training at every level			But successful retrofit also done in Erzincan and Ceyhan	

Table 8 continued

Country	Perceived successes	Perceived Failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
China	Completion of and application of new earthquake design code in 1989 Reinforcement of many existing unreinforced masonry buildings in earthquake-prone areas sinceTangshan Mapping of earthquake-prone areas Successful prediction of the Haicheng earthquake in 1975 Surveys of earthquake damage	Lack of prediction of the Tangshan earthquake of 1976 Vulnerability of buildings in rural areas or built before the 1989 code.	It is believed that implementation of the 1989 code has been good, but recent pace of development has resulted in shortage of skilled workers, and construction quality in uncertain, especially for small projects	In big cities ratio of pre 1989 buildings is less than 10%. Elsewhere the ratio is 10–40%.	Yes, major retrofitting programmes took place over a wide area after the 1976 earthquake.	Aizu Ren Weimin Dong

Table 9 Successes and failures country table: growing risks

Country	Perceived successes	Perceived failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
India	Development of the India Seismic Design Code in 1962; further upgrading in 1966,1970,1975, 1984; and associated earthquake zonation map. Extension of national seismic network Establishment of research and training centres in Roorkee and IIT Kanpur. promotion through courses for academic and professionals in NICEE. Development of simple earthquake resistant house types such as Assam House, Dhijji Diwari (Kashmir), Quetta bond.	Failure to establish an effective legal system of code compliance Lack of enforcement of code. Lack of expertise among structural engineering professionals Lack of supervision on site Unsafe precast construction technology used for government built school buildings	Very poor. OK in government buildings, largely absent in private, ie residential, construction.	Not known	None	Sudhir Jain,

Table 9 continued

Country	Perceived successes	Perceived failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Incorporation of earthquake-resistance in post-earthquake reconstruction in Gujurat and Latur districts. Establishment of an effective compliance system for rebuilt towns in Katchchh.	Decline in capability of artisans and technicians in the building industry Cosmetic repair after the Gujarat earthquake				
Iran	Development and introduction in 1987 of the Iranian Code for Seismic Design. Law making its provisions mandatory for all new buildings Establishment of IIEES with UNESCO support in 1989	Weak law enforcement, so that only a small percentage of all buildings are built to the code Code does not include rural housing Retrofit guidelines do not address most existing masonry buildings, more than 70% of the country's buildings.	Less than 15% of the new buildings are built according to the code, due to ignorance by the public, and lack of proper law enforcement in the building industry	Around 90%	Few retrofits done so far, because of cost limitations but planning for Integrated Disaster Risk Mitigation Plan in progress.	Mahmood Hosseini

Table 9 continued

Country	Perceived successes	Perceived failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Preparation of national guidelines on Seismic Retrofit of Existing Buildings. Law requiring retrofit to be applied to all existing government and public buildings.					
Nepal	Increase in awareness of earthquake risk since 1988 Udaypur earthquake, and corresponding increase in demand for earthquake risk reduction plans. Establishment of NSET to implement National Building Code.	Many demonstrated initiatives have not been adopted nationally. Lack of emergency response system.	Poor control due to: Lack of capacity in the municipalities who do not accept responsibility to provide for safety of residents:	An estimated 60% of existing building stock in Kathmandu Valley would be destroyed by a MMI = IX earthquake. Only 7% of new construction is estimated to be engineered, and quality of construction material and process is poor, with high level of corruption.	NSET has demonstrated feasibility of school retrofit, and has carried out demonstration projects. Methodology exists, but there is no organised programme nationally. NSET has also assessed vulnerability of hospitals, and some offices and private homes; a few retrofits have been carried out.	Amod Dixit

Table 9 continued

Country	Perceived successes	Perceived failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Implementation of a range of Earthquake Risk Management Programmes, through NSET with support from outside agencies (GHI, EMI). Establishment of programme for school safety, and associated programme for training of masons	High disaster risk still exists and is increasing as new vulnerable structures are being built. Government engineering institute does not include earthquake code as compulsory for undergraduate or technician courses. NSET has inadequate capacity to deal with requests for assistance	Issue of permits is treated as a revenue-generating process. Insufficient trained people, engineers building inspectors or disaster managers to control new construction			
Algeria	Improvements in the Algerian Seismic Code Better public awareness of the importance of the code	Lack of control of construction process—no requirement to have engineer's approval National natural catastrophe insurance scheme not a success.	Design work is good, but poor control over construction	Built before the 1983 code: 50% in major cities, 20-30% elsewhere	Some studies done to assess unsafe buildings. Strengthening done for parts of a major hospital in Algiers	Mahmoud Bensaibi

Table 9 continued

Country	Perceived successes	Perceived failures	Code implementation	% of unsafe buildings	Strengthening programmes	Respondents
	Local authorities understand the importance of microzoning studies Good design studies according to code	Lack of quality of materials Concentration of all efforts on the capital, Algiers				
Ghana	Activity from the scientific community to identify risk	Low level of seismic risk on political agenda Lack of information available to the public Majority cannot afford to build earthquake-resistant structures	1996 National building regulations do call for seismic design, but methods to be used are not specified, and not implemented	90% of buildings in Southern Ghana of adobe or brick/block masonry, but small proportion will collapse	No retrofit carried out. Seismic standards for hospitals currently being formulated	Titus Kuuyuor

Reflecting on these responses, it seems possible to separate them into four separate groups of countries. In the first group are what we could describe as the "success stories". These countries have made demonstrable progress in tackling their earthquake risk and reducing it to a level much lower than existed 50 years ago; in each country there remain problems to be tackled, but there has been, and is, measurable progress. Japan, California and Eastern North America, and New Zealand belong to this group. A second group of countries has made some progress over the last 50 years: but it is relatively slow and limited progress. Overall risks are lower than they were, but many high risks remain, and much remains to be done to raise the awareness of the public and the government in order to tackle earthquake risk in a sustained and effective way. In this category of "slow progressers" are most of the European countries. A third group of countries may be described as "movers"; starting from a relatively high level of risk until recently, much has and is being done to raise awareness, and to tackle the high risks which exist in the country: China, Colombia, Turkey and the Caribbean belong to this group. A final, large and most worrying group are those countries in which risks are already high, but, in spite of the best efforts of a few dedicated professionals, little is being done at a national level to tackle the legacy of risk or to control its causes, and consequently risks are continuing to rise alarmingly. In this "growing risk" category are Iran, India, Nepal and Algeria and several other countries.

In the following sections some of the achievements and problems of each of these groups are considered, as the respondents view them, and some overall conclusions are drawn from the results of the survey. Inevitably the results are not uniform, and their depth and the perceptions reported depend on the respondent and the extent of the response. But some pattern emerges.

3.2 Success stories: California, Eastern North America, Japan, New Zealand

3.2.1 California

California is widely and justifiably seen as the global leader in developing and implementing seismic safety policy. It is a good example of how the experience of major damaging earthquakes (particularly the 1906 San Francisco event and the 1933 Long Beach event) have acted as catalysts to a succession of legislative measures leading to subsequent action, as well as stimulating research (Olsen 2003; Perkins et al. 2006; Olshansky 2005). Much of California's success thus derives from actions which were initiated before the starting date of our survey, 1960. But more recent events, especially the Loma Prieta event of 1989, and the 1994 Northridge earthquake, identified continuing weaknesses, and created incentives to continue activity already underway. California's wealth is obviously a great asset in enabling ideas to be turned into action on the existing building stock; but democracy and local autonomy has often been an obstacle to state-wide action, and profit-conscious building owners have frequently resisted proposed upgrading efforts. Thus, even here, our respondents identify several significant failures over the last 50 years and much that still needs to be done.

Successes identified by our respondents are of three types: legislation leading to action; research and the development of technical methods; and market-driven mitigation. Even though it dates from 1933, the Field Act is cited by our respondents as an example of a hugely successful piece of legislation. Coming within months after the 1933 Long Beach earthquake (which would have killed many school-children if it had occurred during school hours), the detailed work that produced the legislation was actually the product of the 1925 Santa Barbara earthquake. The Field Act provided for "the safety in the design and construction of public school buildings, providing for regulation, inspection and supervision of the construction, reconstruction or alteration of or addition to public school buildings and for the inspection of existing school buildings". This ensured that public schools built or altered in California after that date would be earthquake safe, and although it was not retrospective, the inspections which occurred quickly led to upgrading or replacement of many existing buildings—although it was not until 1990 that all pre-1933 school buildings were upgraded or abandoned. Moreover, it provided a model for such legislation, and, in more recent years, has been followed by the Hospital Seismic Safety Act of 1972, and the Unreinforced Masonry Act of 1985 (which has facilitated the retrofit of about half of the 25,000 such buildings in the highest risk zone, Zone 4). Further upgrading successes of the last 50 years are the retrofitting of many public buildings, including offices, libraries, police and fire stations, and many university buildings, as well as highway structures and dams. The City of Berkeley, by means of tax transfer incentives, has enabled 50–60% of its single-family dwellings to be upgraded; other local jurisdictions are following. And State-wide, through effective licensing of all the professionals involved, civil and structural engineers, architects and geologists, the implementation of Codes of Practice is good.

A second strand of success in California has been the huge and sustained research effort to understand the hazards and learn to produce more earthquake resistant structures, underpinned by (from a European perspective) impressive state and federal research funding. The 1972 Alquist-Priolo Act, requiring a detailed mapping of all earthquake-capable faults and to prevent construction on them has been a stimulus to hazard research, and since 1977 the USGS has been working together with FEMA, the National Bureau of Standards (NIBS) and the National Science Foundation (NSF) through the National Earthquake Hazards Reduction Programme (NEHRP), which has directed both research and the production of appropriate technical standards. As a result California's earthquake codes are now recognised as the most advanced in the world, and they are supplemented by an impressive array of guidance documents. Another important strand of research with global implications has been the establishment of the EERI's Learning from Earthquakes programme, which has ensured that the damage experience from major earthquakes worldwide has been investigated and impressively documented since the mid 1970s.

A further strand of success, more significant in California than perhaps anywhere else, is the growing number of private commercial enterprises, educational and cultural institutions, which are prepared to invest in earthquake safety beyond the minimum level required by the Codes, and to retrofit their existing buildings to make them earthquake safe (Comerio 2004).

Even California, however, is not by any means an unqualified success story. Serious weaknesses were identified in the 1989 Loma Prieta and 1994 Northridge earthquakes, in the former case particularly affecting highway structures, and in the latter case steel frame construction. A significant number of unsafe buildings remain even in the highest risk area. A recent study estimates that a repeat of the 1906 San Francisco earthquake would cause between 800 and 3,400 deaths, and that 50% of these deaths will be caused in just 5% of the building stock, consisting of unreinforced masonry, non-ductile reinforced concrete and soft-storey structures (Kircher et al. 2006). Action to upgrade the building stock has been limited to the highest risk coastal zone, Zone

4, with much less effort devoted to the non-coastal, but still at-risk, Zone 3. And there is today a serious problem with the availability of earthquake insurance. With high deductibles and annual premium rates, fewer that 20% of California homeowners are estimated to carry earthquake insurance (Comerio 2004).

Thus much remains to be done, but California has a high-public awareness of earthquake risk (recently enhanced by events commemorating the 100th anniversary of the 1906 earthquake), and an active research and implementation programme. EERI has recently launched an ambitious research strategy for “Securing Society against Catastrophic Earthquake Losses” (EERI 2003) by tackling some of the remaining weaknesses. How this position has been achieved and whether parts of the experience are transferable elsewhere will be discussed in Sect. 3.6.

3.2.2 Eastern North America

Although its earthquake risk is moderate, and there has been no major damaging earthquake in the last 50 years, the Eastern United States has benefited hugely from the achievements of the National Earthquake Hazards Reduction programme, in place since 1977, and the associated research programmes, which span the entire country, and thus deserves to be counted among the success stories of earthquake protection. Under NEHRP the national earthquake hazard maps have been produced; the seismic design guidelines for new buildings developed by FEMA have been adopted in the International Building Code, which has been incorporated into the local regulations for major cities. The regulatory environment in the United States is highly complex, because each of the States is a separate regulatory body, and building regulations are determined on a city-by-city basis. Thus the rate of adoption of seismic design provisions depends on concerned local activists and professionals, and can be slowed by local interests concerned with the increased costs of development which these provisions will entail.

Major perceived successes are the products of the NEHRP as identified above, and the fact that seismic design provisions are now adopted in the local building codes for some major cities with a known earthquake risk, notably Boston (in 1970s), New York City (in 1990s) and Charleston (SC), which experienced a destructive earthquake in 1886. These new regulations have now been applied to the design of billions of dollars of new construction. Another somewhat related success was the fact that earthquake engineers, through previous work in ATC-20 on the development of protocols for post-earthquake damage assessment, were able to rapidly deploy inspection teams, after the 11 September 2001 attack, to identify the condition of hundreds of buildings affected by the collapse of the World Trade Centre.

Conversely, perceived failures are the current lack of any regulations to address the seismic risk associated with older pre-code buildings. In the cities of Eastern North America there are many thousands of old unreinforced masonry structures, forming in fact the core of the historic cites of the region, and many of these are very vulnerable to earthquakes which could occur. New York City has recently adopted a new code on existing buildings which includes no seismic design provisions for pre-2002 buildings. Upgrading or strengthening remains voluntary, and has been very limited. A second perceived failure is that the general public does not understand seismic risk, and this has affected the acceptability of earthquake design provisions by local administrations. Where they have been adopted, it has often been as a result of an extensive campaign of advocacy (Olshansky 2005), to overcome resistance based on

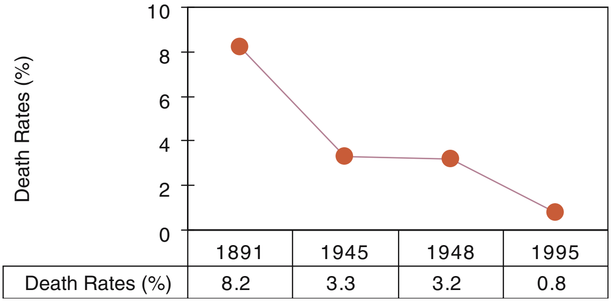


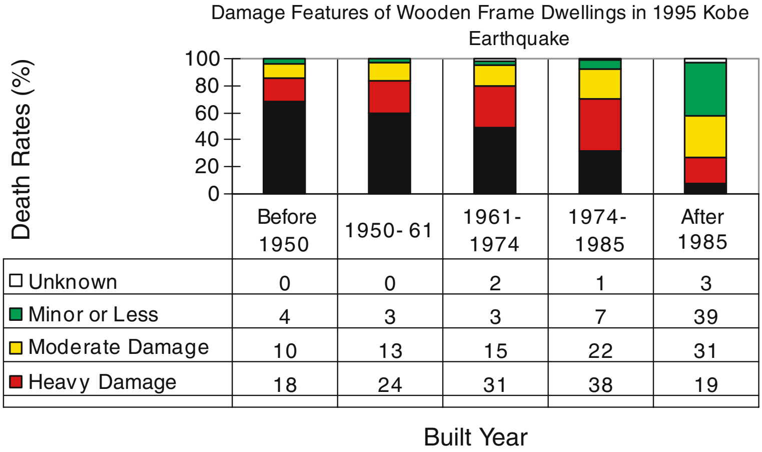
Fig. 41 Comparative death rates in the epicentral area of four major Japaese earthquakes, 1891–1995 (source: Y. Ohta, unpublished data)

the expected extra costs of construction involved. There are a number of known earthquake risk areas for which there are still no seismic provisions in place.

3.2.3 Japan

As in California, progress towards earthquake protection in Japan has been stimulated by the experience of a series of major damaging earthquakes. The 1891 Nobi earthquake demonstrated that European-style brick masonry was not appropriate for Japan. The 1923 Kanto earthquake, with its terrible fire following, showed both the strength and weakness of wood frame construction: it is resistant to ground shaking, but susceptible to fire, as a result of which much effort was subsequently devoted to fire-proof construction. Shortly after the Second World War further earthquakes took place in 1945 (Mikawa Region) and in 1948 (Fukui region), both resulting in several thousand more deaths; and following this, in 1950, a completely new building code was written, which was early enough to have affected the post-war construction. In 1981, another major renovation of the building code was introduced, introducing ductility rules. The benefits of these successive improvements in the code can be seen in the substantial decline in death rates over 100 years (Fig. 41). This compares death rates close to the causative fault for four magnitude >7 events. In 1891, the death rate was around 10%, but this declined to less than 1% by the time of the Kobe earthquake of 1995. An alternative view of improving performance is shown in Fig. 42, which shows damage statistics for wooden dwellings in the Kobe earthquake: 68% of pre-1950 buildings collapsed, whereas only 8% of post-1985 buildings collapsed.

While well-implemented codes and building regulations are at the core of Japan's progress, the parallel research effort has also been a significant factor. Intense historical studies of past earthquakes has led to an very complete 1,500-year earthquake calatogue; Japan has the world's densest array of seismographs and strong motion instruments; Japan produced the first probabilistic hazard map in 1951; and today leads the world in the application of real-time earthquake warnings (braking of Shinkansen trains, and immobilising lifts on arrival of the P-wave). Base-isolation and other energy-absorption system have rapidly become adopted and are now commonplace on modern high-rise buildings. And in Shizuoka Prefecture (Tokai Region), where seismic hazard studies have shown that a large earthquake must be expected, this has led to the funding of major retrofits of public facilities, and coastal tsunami protection works.



	Before 1950	1950- 61	1961- 1974	1974- 1985	After 1985
☐ Unknown	0	0	2	1	3
🟩 Minor or Less	4	3	3	7	39
🟨 Moderate Damage	10	13	15	22	31
🟥 Heavy Damage	18	24	31	38	19

Fig. 42 Comparison of the performance of wooden frame buildings of different ages in the 1995 Kobe earthquake (Source: Y. Ohta, unpublished data)

The perceived failings of earthquake protection in Japan are also notable. Most important, rather little has been achieved in strengthening the many earlier (pre-1981) buildings shown to be vulnerable in the Kobe earthquake. In the high-risk Shizuoka Prefecture it is estimated that half of the 1.21 million wooden houses need retrofitting as recommended by government, but the actual rate is no more than 300 houses per year. There are also 23,000 pre-1981 apartment blocks so far untouched. Government has recently (2004) agreed that retrofitting can be carried out to a lower standard than the current code, and this has resulted in some rise in the retrofit rate. But retrofitting remains the owner's responsibility, and it is not happening. An alarming recent discovery is that, following a move to out-source design approval for new construction from government to the private sector, a significant number of RC apartment and hotel buildings are now known to have been given approval on the basis of a sound design, but what was subsequently built did not conform to the design. And there is some concern about the possible effects of long-period motions from offshore earthquakes on structures such as high-rise buildings and oil tanks. Finally, it is worth noting that earthquake insurance is Japan is weak; the state will cover only a small fraction (about 3%) of potential losses, and, as in California, most households have no additional cover.

Japan has accomplished much but there is still much to do. Considerable efforts are put into earthquake awareness and the public is well-informed about how to behave in an earthquake. But neither householders nor the government are willing or able to accept the financial burden of the upgrading work now known to be required.

3.2.4 New Zealand

As in Japan and California, it was the experience of a really devastating earthquake—the 1931 Hawkes Bay, which destroyed much of Napier and surrounding towns—which pushed New Zealand on the path to its acknowledged status as one of the leading countries in earthquake risk reduction worldwide. However, unlike Japan and California, earthquake losses since 1931 have not been huge, and the two most notable events, the 1942 Wairapa the 1987 Edgecumbe earthquakes did not cause many casualties. Thus, what has propelled New Zealand towards earthquake risk reduction is more the awareness of a well-educated public of the earthquake risk and the potential for a disaster, than the experience of continual disasters.

As in Japan and California, the perceived successes are in a culture of research feeding into technical innovations and leading to improved codes and regulations for building. Most outstanding, and internationally recognised, has been the research at Canterbury University on the behaviour of reinforced concrete structures which led to the concept of capacity design, now central to the codes and to the training of engineers, and widely influential internationally. Another New Zealand "first" was the development of the lead-rubber bearing base isolation system and its incorporation into the 1978 William Clayton building, though this technology has not been as widely adopted in New Zealand as in Japan. Code development has proceeded independently of codes elsewhere, but the New Zealand codes have, since the first code was developed in 1935, been consistently ahead of their time, and their application in new buildings has been effective. New Zealand was also, in 1968, the first country to have adopted legislation allowing local authorities to take powers to identify earthquake risk buildings (mostly of unreinforced masonry) and require them to be upgraded. In the capital, Wellington, 405 such buildings were identified, and their upgrading was required by 2000; a substantial programme of upgrading did take place, and about 90% of the old URM buildings were upgraded or demolished. Since 2004 attention has been focussed on the "brittle" pre-1976 reinforced concrete frame buildings, and new legislation, backed by technical documents developed by the New Zealand Society for Earthquake Engineering (NZSEE), will enable a start to the retrofitting of these buildings. Schools (but not yet hospitals) have been upgraded. Another New Zealand success is that unlike Japan and California, there is a successful national insurance scheme for both domestic and commercial property. This has been in place since 1940, and costs homeowners a modest and affordable 0.05% of the sum insured; the conditions of insurance require certain basic standards of earthquake resistance, leading to a progressive reduction in some of the worst risks.

New Zealand's perceived failures can be regarded as qualifications to this general success story, and to some extent a reflection of the fact that New Zealand's economy is not nearly as successful as that of Japan or California. The Codes are now long and complex and many engineers have difficulty following them. There are no regulations for much plant and equipment and codes for building services are inadequate. There is a lack of Government funding for the further development of codes, and a perceived decline in the level of technical development and training of engineers within the industry brought about by intense fee competition. The progress towards retrofitting of the brittle pre-1976 reinforced concrete buildings has been slow. And, at an emergency management level, there are progressively fewer hospital beds available, calling into question New Zealand's ability to cope with a large earthquake.

New Zealanders believe their efforts have led to an earthquake-conscious society as safe against expected events as anywhere in the world. But this confidence has yet to be tested: as Megget (2006) puts it "we are still waiting for the big one in NZ to confirm that we have done it right with our capacity design approach, ductility requirements in the plastic hinge zones and the detailing required to achieve these ductilities". Nevertheless New Zealand's achievements are admired and copied worldwide, and New Zealand's specialists are actively involved in many global mitigation projects including those in developing countries.

3.3 Slow progress: Europe

This group of countries, while relatively affluent, have made much less progress towards an earthquake-safe society than the first group. A major reason for this is that the recurrence rate of large magnitude and highly destructive earthquakes is much lower than for the first group. For almost a generation, since the 1980 Irpinia earthquake, there has been no event causing more than 1,000 deaths in any of these countries, and as a consequence, earthquake protection has not been as high as it should be on the public agenda, given the significant potential for large earthquakes which exists. But the perceived successes and failures differ considerably between countries, as we shall see.

3.3.1 Greece

Of all the countries in this group, Greece is perhaps the most earthquake-aware, and in some respects deserves to be described as a success story. However its relatively low level of affluence has limited its ability to put many necessary earthquake-protection measures into place. Over the last 50 years, the public's perception of the earthquake risk has been frequently jolted by damaging events which have caused human casualties. Coming shortly after the war years, it was the major Ionian Islands earthquake series of August 1953, which devastated the islands of Cephalonia and Zakinthos causing 476 deaths, which started the process towards the production of the first Greek Code in 1959. Four further events occurred during the 1960s, causing about 50 deaths between them, but these were rural events. Since 1978 the most significant earthquakes have been close enough to affect urban areas—Thessaloniki in 1978, Athens in 1981 and 1999, Kalamata in 1986 and Aeghion in 1995—causing 257 further deaths, and enormous economic losses (Pomonis, 2001). As a result of these urban disasters, the Greek earthquake code was upgraded three times in this period, in 1984, 1995 and again in 2004.

As well as the relatively low-death tolls in the frequent earthquakes, the high earthquake risk awareness of the general population is perceived as the basis of Greece's earthquake protection success. This has led to a rapid government response to earthquakes in revising the building code and the seismic zonation, and a demand by the public for safer buildings. Standards of urban construction improved after the 1978 and 1981 earthquakes caused serious damage in the two major cities; the training of engineers in this subject is perhaps the best in Europe, leading to a good standard of Code implementation in all engineered construction; and there are major well-equipped research centres in both Athens and Thessaloniki and other Universities. The Greek government has also set up a national Earthquake Planning and Protection Organisation (OASP), founded in 1983, to plan and oversee a national policy for earthquake protection. As well as assembling data on earthquake damage and losses and commissioning research, the activity of OASP has led to significant action to mitigate losses through evaluating and upgrading the existing stock of public buildings. A programme is in place to assess the safety of all school buildings, as well as the hospitals in the major cities.

But these successes are tempered by a number of perceived failures. Much of the pre-1984 urban construction, comprising nearly 80% of the country's residential building stock, is considered substandard by today's understanding, even if built to the 1959 code, and some of this building stock, particularly the 30% built during the post-war boom before 1960, may be unsafe. Even today there is perceived to be poor training of the site workforce and inadequate supervision of much of what is built; there is poor urban development and land-use planning leading to inappropriately sited developments; and corruption is commonplace. And, although procedures are in place for the assessment of public schools and hospitals, because of the poor state of the Greek public finances (Greece has the highest debt ratio among the 25 EU countries), progress in this assessment is very slow, and almost no strengthening has so far been done.

3.3.2 Italy

Italy is like Greece in having very extensive areas of high seismicity and a history of damaging earthquakes, but unlike Greece, much of its population and most of its major cities—Rome, Milan, Florence—are located in regions of relatively low seismicity. Action towards the development of a national seismic building code started earlier than elsewhere in Europe, after the huge Messina disaster of 1908 which killed over 80,000: but the seismic zonation of the time applied only to the south of the country. The events of Friuli in 1976, killing 929 people and Irpinia in 1980, killing 4680 people, showed the very high vulnerability of much of the traditional masonry building stock (Fig. 2) and triggered the production of a national seismic zonation, which brought many additional areas under the seismic building code. But further fatalities in the Umbria-Marche earthquake of 1997, and particularly the Molise earthquake of 2002, triggered both a new code and seismic zonation, and a programme for the assessment and strengthening of existing buildings. The Molise event, a comparatively small ($Mw = 5.7$) event, which caused the collapse of one school building in San Giuliano, killing 27 pupils and their teachers (Fig. 43) was particularly tragic and shocking to the nation, because the area had not previously been classified as a seismic area, and the masonry school building had recently been modified in ways which were unsafe in an earthquake area. Rapid action by the government resulted in the formulation of a new seismic code and seismic zonation, and a number of actions to stimulate intervention in the existing vulnerable building stock. Unlike many countries in which the building code is a national standard, adopted within the contract and specification for a new building, in Italy the entire Code, and the associated seismic zonation, has the status of a law, and must thus pass through parliament, a slow and cumbersome process which can easily be upset by changes of government.

Perceived successes of earthquake protection in Italy are the formulation of the first seismic code in 1909, its upgrading in 1984 and in 2003, and its application in the construction of many buildings in the defined high-risk areas. Italy, like Greece, has a well-developed programme of earthquake–engineering training in its Universities, and many excellent research centres for earthquake engineering research. In addition substantial upgrading of buildings affected by 1976 and subsequent earthquakes has taken place, under programmes funded by the central government and the regions. Also, since 2002, plans have been put in place for the seismic assessment and upgrading of key strategic buildings and schools, and in some high-risk regions (e.g. in Eastern Sicily), residential buildings also.

Perceived failures in Italy are the government's slowness in adopting new seismic codes and zonations (partly for the reasons explained above) after previous earthquakes. This has meant that before 1976 only about 20% of all *comuni* in Italy required any level of seismic design, compared with 55% today. As a result much of the

Fig. 43 San Giuliano, October 2002: school collapse which killed 27 children and their teachers (Source: www.oecd.org)

construction in Italy during the post-war years was built with no attention to seismic loading. In 1991, although 45% of the country was classified as seismic, only 14% of the buildings were built to earthquake–resistant design standards. Thus, in addition to the many remaining low-strength masonry buildings from the pre-war period, the bulk of post-war reinforced concrete is below today's standards, and much of it may be unsafe. Other perceived failures are that in recent years, there has been difficulty in the application of the new 2003 code, because of many postponements, and because engineers are perceived to have difficulty in understanding some of the new concepts. And, while programmes are in place for the evaluation and strengthening of existing buildings, both a lack of resources and difficulties in deciding on prioritisation means that this strengthening is proceeding very slowly.

3.3.3 Portugal

Portugal appears on the European seismic hazard map (Giardini et al. 2003) as a country of only moderate seismicity, yet, in 1755, it suffered the most catastrophic European earthquake disaster of the last millennium. There is still no scientific consensus on the origin or magnitude of that event (Gutscher 2005), but the level of ground shaking was clearly sufficient to cause immense and widespread destruction, further aggravated by the effects of a massive tsunami. Lisbon's metropolitan area is also affected by earthquakes of relatively smaller magnitude from the much closer fault system in the Lower Tagus Valley, though the last earthquake in this area to cause any destruction and human casualty was the 1909 $M = 6.1$ Benevente earthquake. The Azores region is frequently damaged by moderate-sized earthquakes, notably in the island of Terceira in 1980 and Faial in 1998. The long experience of earthquakes in Portugal has resulted in active scientific and earthquake engineering communities, but the uncertainty about the hazard in continental Portugal has made it difficult for this to be translated into effective action for earthquake risk mitigation.

Perceived successes in Portugal include the development of a high level of research and academic expertise in the Universities and national research institutes like LNEC, leading to a good standard of professional education in earthquake engineering and a very important contribution to the development of the latest international generation of earthquake codes (especially EC8 (EN 1998-1(2004))). There has been a significant effort to engage with the media leading to an increase in public awareness of the earthquake issue—the 250th anniversary in 2005 of the 1755 earthquake was successfully exploited in this way—and some improvement in the standard of construction. After the Azores earthquake of 1998, the publicly funded rebuilding programme required that strengthening be carried out alongside repair, even for ordinary residential buildings. And a 20-year nation programme of action for earthquake risk mitigation has been formulated by the Portuguese Society for Earthquake Engineering.

Portugal's main perceived failure is that there remain large numbers of buildings built before 1980 which are vulnerable to expected levels of earthquake ground shaking, but apart from the Azores, there is as yet no national commitment to a programme of risk reduction in the existing building stock. An estimated 22–25% of the building stock was built before 1930 in masonry, and another 30–35% consists of pre-1980 reinforced concrete, all of which has poor seismic resistance. The need for strengthening of a number of public buildings such as schools and hospitals has been identified, but there is no programme in place to undertake this work, and no guidelines for the retrofitting of vulnerable structures have been developed. A further perceived failure is the lack of professional consensus on the level of seismic hazard facing the country, partly the result of poor communication between the scientific and the engineering communities.

3.3.4 Romania

All of Romania's large earthquakes occur in the relatively small Vrancea region in the Carpathian Mountains, an area which is itself not densely populated. But these are deep earthquakes, and as a result are felt over a wide area, and can be very destructive in areas of deep alluvial soils, such as the capital Bucharest. Tall buildings are particularly at risk. Three major events have occurred in twentieth century. That in 1940 killed 350 people, while the most lethal in 1977 killed nearly 1,600, over 90% of them in Bucharest, and destroyed 33,000 dwellings, mostly in the high-rise apartment buildings which were by then widespread (Fig. 44). The legacy of this earthquake, and a further smaller shock in 1990 (Pomonis et al. 1990), has been considerable attention to earthquake-resistant construction especially in Bucharest, and the development of an active, and internationally well-integrated, earthquake research culture.

Romania's perceived successes have been in the development of a regulatory basis for earthquake-resistant design, with a code introduced in 1963, then updated no less than five times, in 1970, 1978, 1981, 1993 and 1996, keeping the codes well in line with international developments of the time; and simultaneously the development of a high-quality system for the training of engineers. During the socialist period, design was carried out in large design institutes which supported specialist staff, and implementation is thought to have been good.

Fig. 44 Bucharest: apartment block damaged by the 1977 earthquake; many such apartment blocks were poorly repaired after the earthquake and upgrading is now in progress (Source: INCERC, Romania)

> “The most visible and undeniable success is shown by the outcome of the 1977 earthquake: about 90% of the buildings which collapsed were nominally unprotected, ie built before the war. Just 3 nominally protected buildings partially collapsed”. (H. Sandi 2006, Personal Communication)

Further, a programme exists for the evaluation and strengthening of schools and hospitals, as well as other important buildings and many upgrading projects have been carried out.

Romania’s failures are perceived to be the substantial residue of residential buildings damaged by the 1977 earthquake which were only cosmetically repaired at that time, and still, in spite of a government programme, awaiting proper strengthening. There are about 100 such buildings in Bucharest, but only 10% of them have so far been acted on. In addition, the pressures of the market economy have led, since 1989, to a lowering of the standards of training of the engineers and of the quality of design, and difficulties with the future implementation of the more complex EC8 are foreseen. According to H. Sandi (2006 unpublished data), what this amounts to is that “. . . a disaster prevention culture is not yet sufficiently developed” in the country.

3.3.5 Slovenia

Until the 1980s break-up, Slovenia’s development of earthquake codes was that of Yugoslavia. The tragic Skopje earthquake in 1963, which killed 1,100 people, followed by the larger though less lethal Montenegro event in 1979, provided a huge boost to that effort. Slovenia’s earthquake-awareness was also stimulated by the severe damage caused by the 1976 Friuli earthquake, whose epicentre was just across the Italian border. The code introduced in 1963 was updated in 1981. Perceived success in Slovenia are the successful implementation of the codes since 1963, and the relatively high knowledge of earthquake engineering among structural engineers. A rapid assessment of school buildings has been done, and some strengthening carried out of the highest risk buildings.

Correspondingly, the failures are the late adoption of the code, with the result that a large number of buildings and civil engineering structures built after the war are unprotected and some (including several 10–13 storey unreinforced masonry structures in the capital Ljubljana), are unsafe, and the fact that there is currently no programme in place to remove or strengthen such buildings. As in Romania, problems are expected with the implementation of EC8, because it is a demanding standard, but also because there has been no recent earthquake nearby, and because the demands of a market economy make it difficult to maintain high standards of design. A law requiring the assessment and strengthening of important buildings was passed 20 years ago, but funds have not been made available to implement it.

3.3.6 Russia

Until 1989, the Soviet Union (USSR), controlled a vast territory much of which was prone to earthquakes, particularly the Pacific margin and the Central Asian republics of Uzbekistan and Kazakhstan. It was in the then Soviet republic of Armenia that the 1988 Spitak earthquake occurred, killing 25,000 people, as described earlier. Altogether there were 44 fatal earthquakes in the former USSR territories in twentieth century, killing 75,000 people (Coburn and Spence 2002). As a result the USSR was one of the earliest adopters of modern seismic requirements for building, introducing its State Seismic Building Code in 1957, with the first use of a standard response spectrum design approach. Within the Soviet state system, a rather effective way of ensuring code implementation was created.

Russia's perceived successes are the early introduction of this building code and its implementation, and several other innovations. For the construction of mass housing after the war, the USSR developed a prefabricated wall-panel system of construction which has been very successful in resisting subsequent earthquakes, as shown in the Spitak earthquake (Section 2). Indeed it is claimed (Eisenberg 2006 Personal Communication) that there is not a single instance of the collapse of such a building in an earthquake. Russia also pioneered the development and widespread application of semi-isolated structures, using sliding supports, rocking columns, and sacrificial elements; developed and built large (100 tonne) earthquake shaking tables and exciters in the 1960s, and has recently adopted a seismic zonation with maps of several different design loading intensities.

On the debit side, the perceived failures are that in today's Russia, there is little state support for engineering research and very poor interaction between Russia and the international scientific community. There has been, since 1989, a decline in the standards of design through the break-up of the large design institutes following market reforms; the construction (as opposed to design) quality of much mass housing is poor. A large proportion of today's housing is substandard and, although a programme (Seismic Disaster Mitigation 2002–2010) has been in place since 2002 for the evaluation of existing buildings, progress has been small due to lack of funding for the strengthening work involved, and for the necessary underpinning research into prioritisation.

3.3.7 France, Spain and Austria

All of these countries have areas of moderate seismicity, and have experienced damaging earthquakes in the past. But their experience of earthquakes in twentieth century has been limited. In France, the earthquake risk is mainly concentrated in the south west, in the Provinces of Savoie and Provence. The only twentieth century deaths occurred in the Haut Provence Lambesc earthquake in 1909, which caused 46 deaths, but several other earthquakes have caused significant damage, as for instance in 1996 a $M = 6$ earthquake near Annecy. The Caribbean territories of Guadeloupe and Martinique have a higher risk, and an $M = 6.3$ earthquake occurred near Guadeloupe in 2004 resulting, fortunately, in only one death. In Spain, earthquake risk is concentrated in the southern Provinces of Murcia and Andalucia , where several lethal earthquakes have occurred, most recently in February 1999, and to a smaller extent in the Pyrenees. In Austria the southern province of Kärnten and Steiermark are most at risk, but there is no recent experience of earthquake damage. All of these countries now have their own earthquake loading codes, which are in the process of being harmonised with the Eurocode EC8, but general awareness of the earthquake risk is low among the population, and in the construction industry.

Perceived successes in all three countries have been the introduction of earthquake-resistant design regulations, and the activity of the national earthquake engineering communities (AFPS in France) in preparing the basis for these regulations. In Spain this has been since 1968, with subsequent updates in 1974, 1992 and 2002, but in France only since 1991 for ordinary buildings. Application of these codes in design, thanks to training efforts (again in France due to AFPS), is thought to have been relatively good. In all three countries, activity has recently been started to identify some of the highest risks among public buildings, so that strengthening action can be taken. In France and Spain this has been concentrated on the cities with the greatest risk, Nice and Barcelona, and in Austria the activity has been in Vienna. In France, a law requiring all substantial modifications to existing buildings to comply with current design requirements has led to some strengthening work, both in Nice and in Guadeloupe. But such action so far is very limited.

In all three countries the perceived failures are a lack of adequate quality control of what is built on site, and a still limited understanding by ordinary design professionals of seismic design concepts. In Spain it is reported that even when buildings are designed to required earthquake loading, the detailing of the structural members required for ductile performance in earthquakes is often missing; and flat slab or waffle slab designs (with their inherent weakness in earthquakes) are often used for multi-storey construction. Because of the late application of the code, a high proportion of the national building stock in each country is below current regulations, but it is thought that buildings constructed according to existing codes for concrete and steel would survive the expected moderate earthquakes. Many masonry buildings however may be at risk.

3.4 Movers: progress from a low base

This group of relatively poor countries or regions, starting from a situation of very high relative risk, has in recent years been making significant progress towards identifying, understanding and tackling their earthquake risks, and giving them a higher profile in national development planning. There seems also to be a growing public awareness of the importance of earthquake protection. In nearly all cases this has been triggered by relatively recent experience of a damaging event; it may also be connected with significant progress in national economic development.

3.4.1 Colombia

Colombia is located in a highly active earthquake zone, where three major tectonic plates converge. Its capital Bogota, is in a zone of intermediate hazard, and major cities such as Cali, Manizales and Popayan, lie in the region of highest seismic hazard. Over the last 500 years more than 50 earthquakes greater than magnitude 7 have hit Colombia. The most recent disaster, the $M = 6.2$ Armenia earthquake of 1999, killed 1,200 people. This long earthquake experience has been an important stimulus to national efforts to reduce earthquake risk. This has not only involved developing and updating a national seismic building code in line with the international state-of-the-art, but also efforts to develop and promote appropriate guidance tools for non-experts and builders; and a start has been made on retrofitting important public buildings.

Perceived successes are the development of the national seismic code for buildings, in 1984, updated in 1997 and several times subsequently, including provisions for bridges. An important chapter of that code provided simplified rules for one and two storey buildings aimed at both designers and small builders, which became the basis of training programmes. Universities have good training programmes, and graduates understand and can use the code. From this has followed the development of a manual for designing small RC buildings in earthquake areas, which has been adopted internationally, through the American Concrete Institute and the International Standards Organisation (ISO). Universities have been active in research on local materials—particularly adobe and bamboo (the *bahareque* system)—and this has led to guidelines for the repair of historic adobe structures, and inclusion in the building code of structural requirements for the design and construction of *bahareque* dwellings. There have been in-depth microzonation studies of some cities: Bogota and Manizales have detailed studies of seismic risk, building-by-building, local seismic protection policies and insurance schemes. In addition, funds have been obtained from the World Bank to start a programme of strengthening of the public schools, main hospitals and bridges in Bogota. The need for retrofitting is accepted not only by engineers but also by decision-makers, but is limited by resources and political feasibility.

The major perceived failure in Colombia is in the informal sector, responsible for at least half of all that is built. Buildings in this sector are not built to code standards, and although some may have been built using the published guidelines, there is insufficient funding to enable these to reach the mass of individual builders. In Bogota, about 60% of all buildings predate the first seismic code. Adding to this the high percentage of post-1985 buildings, perhaps 50%, not built to code requirements, it appears that about 80% of all buildings may be unsafe in a major earthquake. And there is a huge stock of public buildings in need of strengthening for which the funds and political commitment are not available. In the words of Cardona:

> “It is necessary to be more radical in requesting effectiveness and commitment. If we reinforce one school but we need to intervene in 10,000, the achievement is nothing….The problem grows faster than the velocity of the solutions: this

is the main failure of our social commitment as academics and professionals" (Cardona 2006, Personal Communication).

3.4.2 Caribbean

Although the Caribbean islands are located close to important plate boundaries, and thus at risk from major earthquake ground shaking, the last 50 years have been free of major earthquake disasters; the CRED database records only four deaths since 1960. However, going back further, the north-eastern part of the Dominican Republic was affected by a magnitude 8.1 earthquake in 1946, and in 1907, 1,200 died around Kingston, Jamaica, from an earthquake of magnitude 6.5 (CRED 2006). The earthquake hazard is real, but not well-understood, even by the local engineering profession, and the fragmentation of the Caribbean region into a large number of independent territories (and several languages) means that progress is inevitably patchy. But there are significant successes.

The perceived successes are that earthquake-resistant design requirements are now incorporated in most of the national building standards, and there is a growing awareness of the need to consider earthquakes in designing buildings, particularly in Jamaica, Trinidad and Tobago, Dominican Republic and Puerto Rico. There is a gradual increase in the number of engineers studying earthquake engineering and competent to design earthquake-resistant structures, interest in understanding seismic hazard, and installation of strong-motion instruments. There are some programmes, through the Pan American Health Organisation (PAHO), to undertake vulnerability assessments for existing health-care buildings.

The perceived failures in design are that earthquake-resistant design requirements are often ignored by engineers; even when the earthquake loadings are adopted, the corresponding ductile detailing requirements are poorly understood and usually ignored; architects are unaware of the need to adopt suitable earthquake-resistant forms, and resist attempts by engineers to promote this idea; electrical and mechanical plant are designed without consideration of earthquakes, as are major infrastructural projects. There is also a failure in implementation: unnecessary proliferation of standards documents, poor training in the use of new documents, and inadequate checking on the part of the government regulatory authorities. The vast majority of buildings constructed before 1960 would exhibit no conscious earthquake-resistant design (with the exception of Jamaica), and even now most buildings do not conform to the available standards. But this does not mean that they are unsafe and would collapse.

3.4.3 Turkey

During twentieth century, Turkey has experienced more earthquake disasters than almost any other country. According to Gülkan (2006) and USGS (2006), the total life loss in the century was 97,000; 12 events since 1900 have each caused more than 1,000 deaths; and the events of Kocaeli and Düzce in 1999 (see Section 2), resulting in about 18,000 deaths, as Gülkan puts it "served to awaken the country from the illusion that disasters could be handled as they always had been, through post-event interventions for physical restitution". The fact that the 1999 events were selectively damaging to the most recent construction was a particular concern as Turkey's population has been rapidly urbanising; and added incentive for action was given by the widely publicised and authoritative studies of the post-1999 stress-changes on the north Anatolian Fault System (Parsons et al. 2000), which suggested that an earthquake damaging to the huge metropolitan region of Istanbul was very probable in the next 30 years. Thus, since 1999 Turkey has been among the most active nations in investigating and seeking to reduce its earthquake risk, and no city more so than Istanbul.

Turkey's perceived successes are its current code, updated in 1998 with a new hazard map, and the education and training programme for young engineers which now exist in many Universities. Turkey is highly active in research on all aspects of earthquake risk, with many internationally important research teams; and Turkey has become, in 2006, the permanent base of the European Association for Earthquake Engineering. There has been a great increase in awareness of earthquake risk, both by the public and the urban authorities, in large cities such as Istanbul and Izmir, which has led to both microzonation studies, and retrofitting projects for some major buildings such as hospitals, school, buildings and airports. There has been the development of a new comprehensive legislative approach to disaster management at a national level (Gülkan et al. 1999). And, already conceived before the 1999 earthquake, Turkey introduced a national residential earthquake insurance scheme (DASK) in 2000, offering cover sufficient to ensure that basic reconstruction costs would be paid in return for a relatively modest premium. Although numbers have declined somewhat since, numbers of policies quickly shot to the 2 million mark, making it one of the largest earthquake insurance schemes anywhere.

Turkey's perceived failure lies particularly in the very high degree of vulnerability of most of the urban residential building stock, through rapid population growth, a lack of proper engineering design in many buildings, and an inadequate system of building control both in the design and on site. Also, many of the important provisions for improving construction standards and building control which were issued as decrees following the 1999 earthquake have not been passed into law. As a result there is still poor implementation of earthquake design by many small design firms, whose designs are not properly checked by the municipality. There is a lack of incentives for owners to take steps to undertake their own mitigation actions; and there are no provisions in DASK for reduced premiums if mitigation measures such as upgrading are undertaken. DASK has also been undermined by the national government's continuing practice of compensating disaster victims for the loss of their homes even if they are not insured (as in the Bingol earthquake of 2003). There is a lack of financial support for mitigation measures. In Istanbul it is estimated that given a strong earthquake of the magnitude expected within the next 30–50 years, maybe 10% of ordinary 3–4 storey reinforced concrete apartment blocks will collapse, with irreparable damage to up to 30%.

3.4.4 China

Over the centuries, more lives have been lost in China from earthquakes than in any other country, and twentieth century, with 170 fatal events claiming over 600,000 lives, was no exception. For many decades China has devoted much effort to the earthquake problem. After its system of earthquake prediction astonished the world in 1975, when the city of Haicheng was successfully evacuated shortly before a major earthquake, China briefly thought it had found an effective new solution to the task of life saving in earthquakes. But the occurrence, just over a year later, of the Tangshan

Fig. 45 Student housing in Beijing, 1980, retrofitted with external reinforced concrete frame (Photo by author)

earthquake, with the loss of an estimated 250,000 lives, shook that confidence. The Tangshan event (see Section 2) not only was not predicted but occurred in an area for which no specific earthquake-resistant design was at that time required. Since then, efforts have been concentrated on the more conventional approach of better defining the earthquake risk zones, developing and enforcing an effective code for new construction, and retrofitting many existing buildings in high-risk zones. The full extent of the retrofitting programme is not known, but it has certainly included many public buildings such as schools, hospitals and University residences. It was reported by a visiting US delegation in 1980 that such retrofitting had upgraded over 70 million m^2, and the programme was continuing (Gere and Shah 1984); a Cambridge University team which visited Beijing in the same year was shown examples (Fig. 45). During the last 20 years, urban growth and regeneration has been happening at an enormous pace, and it is believed that much of the resulting building will have been done according to the 1989 code. Since 1976 China has not experienced a major event affecting a large city, so the success of this strategy has yet to be tested.

China's perceived successes of the last 50 years include the development and application of the 1989 code, and its further updating in 2001; better mapping of the earthquake risk areas; and the extensive retrofit programme which took place after 1976. The successful prediction of the Haicheng earthquake is also perceived as a major success. Perceived failures are the failure to predict the Tangshan earthquake (or identify this as an earthquake-risk area), and the continued existence of many buildings, particularly in rural areas, which are not built to earthquake-resistant standards.

3.5 Growing risks

The final grouping in our survey comprises those countries in which, often in spite of considerable efforts by dedicated professionals to improve matters, there is little evidence that earthquake risk is regularly and systematically taken into account in the way ordinary new structures are built, and consequently earthquake risks are not diminishing with time. Indeed, as most of these countries are both relatively poor, and in the process of very rapid urbanisation, it is likely that their earthquake risks are increasing with time. From the evidence of our respondents to this survey, this group has to include Iran, India, Pakistan, Nepal Algeria and Ghana. The responses from India, Iran and Nepal are summarised below. The gist of these responses, plus those from Algeria and Ghana, are also found in Table 9. This is of course not an exhaustive list, and it is probable that a number of other countries in South America and Asia belong to this category. In the immediate future, it is in these countries that we can expect to see major earthquake disasters recurring.

3.5.1 India

India has suffered many huge and deadly earthquakes over the last two centuries. Since the start of twentieth century there were 21 fatal earthquakes, claiming over 50,000 lives between them, the most recent being the Mw = 7.7 Bhuj earthquake of 26 January 2001, which killed over 13,000 (Section 2). The Himalayan Region and the Western parts of Gujarat are particularly at risk. There has been a well-formulated earthquake code in existence in India since 1962, regularly updated. However, until 2001 this code was not mandatory except for government construction, and was ignored by developers for most residential construction. As a result there were many failures of reinforced concrete structures in the 2001 earthquake, even as far away as Ahmedabad. Since 2001 there have been efforts by a growing group of earthquake specialists to promote better understanding of the earthquake problem, and action by municipalities to set up systems to require and ensure code compliance, but success has been limited, and it is thought that much of what is being built today in the major cities is still inadequate to resist a strong earthquake.

Successes include the early formulation of the earthquake code and its updating through a series of reviews, and the maintenance of a high degree of earthquake expertise both at the Indian Geological Survey, and at Universities in Roorkee and IIT Kanpur as well as elsewhere. Since 2001, IIT Kanpur has set up the National Earthquake Information Centre which has been running training programmes for professionals and academics India-wide. After earlier earthquakes, simple housing systems were developed in Assam and Kashmir which are still widely used. In Latur and Katchhh Districts, following the earthquakes of 1993 and 2001, considerable effort was devoted to ensuring reconstructed houses would have better earthquake resistance (Gujurat State, 2002). And in the four worst hit towns in 2001 (Bhuj, Anjar, Bachau and Rapar) an effective system for ensuring seismic code compliance in all new construction has been instituted.

The principal perceived failure is the continued absence of an effective legal system of code compliance. Even in places where municipal engineers do demand a certificate to state that a building complies with seismic codes, this is not effective, as such certificates can easily be obtained without any correlation to how the building is built. There is a general lack of expertise in earthquake design practice among many professional structural engineers active in earthquake zones. Defects in design are compounded by the numerous defects in construction practice, both in the use of poor materials and failing to construct the building according to the design. There is a perceived decline over recent years in the capability of artisans and technicians in the building industry (Jain 2006). And where buildings have been damaged by earthquakes, repair is often purely cosmetic leading to serious weakness in the event of a subsequent shock.

3.5.2 Iran

Iran has a tragic history of large earthquakes with huge death tolls. In twentieth century there was at least one earthquake of $Mw = 7.0$ or above every seven years, and one $6.0 < Mw < 6.9$ event every 2 years, resulting in a death toll of more than 164,000 people since 1900 (Berberian 2006). Earthquake losses have continued to rise in line with the population expansion. The events of Bam (2003) and Manjil (1990), described in Section 2, with death tolls of about 32,000 and 40,000, are the worst in the last 50 years, but there have been many other fatal events in this time. However, as Berberian (2006) points out, none of the large magnitude earthquakes has so far impacted the metropolitan area of Tehran or other provincial capitals, even though many of these are located in earthquake-risk zones. The first national earthquake code was introduced in 1969, and revised in 1988, and updated again in 2005, and application of this code is required by law for all new buildings. This code development, the associated hazard mapping, microzonation and other mitigation activities have been coordinated by the International Institute of Earthquake Engineering and Seismology, established in 1989. However, for a variety of reasons, part of which is the continuing poverty of much of the population, part of which is the turbulent political context of the last 50 years (Tierney 2005), public awareness of the earthquake risk is still low, and enforcement of building standards and building control is still very weak. Thus as urbanisation continues, and in spite of the warning of Manjil and Bam, the existing high levels of risk seem to be getting even higher.

The perceived successes of earthquake protection in Iran are the preparation and successive updating of the seismic design code, and its incorporation into law; and the preparation of the Iranian Guidelines for Retrofit of Existing Buildings, and the legal requirement to apply it to all government and public buildings. Successes also include the establishment of IIEES in 1989 by NATO, and its subsequent activity for understanding and mitigating earthquake risk.

However, set against these successes, the perceived failures are serious. The code does not apply to rural housing, where much of the risk is located. More seriously, law enforcement is so weak that perhaps only 15% of new buildings are estimated to be built according to the code, and as a result an estimated 90% of the buildings in the country are today considered unsafe. The published retrofit guidelines do not address masonry buildings which constitute more than 70% of the existing buildings in the country.

3.5.3 Nepal

Nepal is a small and very poor country which has a history of devastating earthquakes. In 1934 the huge $M = 8.1$ Bihar–Nepal earthquake caused strong ground shaking in the Kathmandu Valley, and destroyed 20% of the valley's building stock; but the urbanisation of the last 50 years has concentrated population in the valley, with declining standards of construction, and this has led to a major concentration of risk (Dixit et al. 2000). Since an $M = 6.6$ earthquake affected much of the country in 1988, some action was initiated by government to try to reduce the risk by establishing a national building code, and, later, by establishing NSET, the National Society of Earthquake Technology, a group of professionals, to help in the implementation of the new code. During the last 10 years the group of dedicated professionals in NSET has been very effective in raising earthquake awareness, assisted by a series of projects involving international consultants (Dixit et al. 2000; Sharpe 2004). But it remains very difficult, in a country facing chronic poverty, to convert that awareness into measurable improvement in building standards.

Perceived successes are the activities of NSET in raising public awareness and technical competence. The School Earthquake Safety Programme involved training of masons, small contractors and building design professionals on earthquake-resistant construction methods; this has resulted in some funding by government, and an association of masons interested in earthquake-resistant construction. There has been a "visible enhancement of earthquake-awareness in all quarters", with replication of earthquake resistant construction even in rural areas. One municipality of Kathmandu has taken the lead in making the national building code mandatory for all new construction, and others have active programmes to encourage its use. There is a demand for earthquake-resistant construction, and this is increasingly being implemented in development projects. Some schemes for retrofitting schools have been carried out.

Percieved failures are that in spite of these successful demonstrations and initiatives, earthquake resistant building techniques are not widely adopted across the country. Even the government-owned engineering institute does not teach the national building code as a required part of their engineering courses. Construction of highly vulnerable buildings continues at a great pace throughout the country. The building code is not implemented because the municipalities lack the organisational structure and skilled manpower, and do not see their role as including the provision of safety for the residents. It has been estimated that no more than 7% of new buildings are engineered in their design, and beyond this, there is corruption, and there are poor materials and quality control in the actual construction process. It has been estimated that 60% of the building stock in the Kathmandu Valley would be destroyed by a MMI = IX intensity earthquake. Although NSET exists to promote earthquake resistant construction its limited resources are overwhelmed in trying to meet the needs.

3.6 Conclusions from this survey

To what extent is it possible to draw some general conclusions from this brief survey of progress in earthquake protection in a few countries: and is it possible to transfer lessons from achievements in one country or set of countries to another?

We start with the not very surprising conclusion that there are two strong determinants of action for earthquake risk mitigation: the first is recent experience of a strong or devastating earthquake, and the second is the availability of resources to take action for mitigation. All of the "success stories" are relatively affluent countries (in the top ten in the UN's Human Development Index, HDI), while the "growing-risk countries" are towards the bottom of the HDI list. Europe, while its level of affluence is not far short of that of the "success stories", is doing relatively little because large earthquakes have been few, and public perception is that the risk is small and localised. The "movers" are countries with growing economies that provide opportunity for national action.

But, in spite of these economic and tectonic determinants there are some lessons which the slow-progressers and high-risk countries can maybe learn from the success-stories and the movers. The first is that public awareness rather than law, is everywhere the most important basis for action. In all countries, the respondents have pointed to their national success in formulating national codes, guidance documents and sometimes laws for earthquake protection. But it is the designers and builders who must apply these codes, and local authorities who must enforce them, and the legal requirements can easily be circumvented when the owners and occupants do not insist on them. It is the informed public, as parents, politicians and concerned citizens who have forced the pace on earthquake risk mitigation; and an informed public is necessary to ensure that building control does get applied.

The second lesson is that education, training and registration of professionals is vital. Understanding earthquakes and how to design buildings to survive them is a complex business, and all the success stories depend on widespread professional training of earthquake engineers as well as professional registration schemes. Lack of professional registration in Turkey is identified as one of its failures in the past (Gülkan 2005); and in India, the lack of a sufficient number of engineers with the appropriate expertise is seen as a serious impediment to progress (Jain 2006).

The third lesson is the great impetus which the experience of damaging earthquakes has given to progress. In the United States years of painstaking planning for mitigation regulations has actually been implemented only in the "window of opportunity" following a major event. The same has been true in Japan, Turkey, Italy and Greece, as reported by our respondents. It seems vital to be prepared with changes in regulations and practices which can then be rapidly implemented in this moment of opportunity. For urban building, there are important lessons which can be learnt from the efforts of Turkey to create an effective system of building control for the cities, following the 1999 Kocaeli disaster.

Some common concerns are also highlighted by these reports. There is a concern about the increasing complexity of the codes of practice, especially in Europe, and a feeling that application may not be achieved as a result. In former communist countries there is a concern that market-reforms are breaking down the well-informed large design bureaus and leading to poor design standards; and in some places where earthquake loading required in the code is adopted, ductile detailing is ignored.

But the most persistent common concern, shared by virtually all the lower-income countries, is that their uncontrolled urbanisation means that the vast majority of the new building stock is built without any concern for earthquake risk. Attempts to create a system of building control are hampered by corruption, and by the attitude that the issue of building permits is a revenue-generating process, not connected with public safety, and this is building up the potential for huge disasters in the future. And where the need for strengthening of key public buildings such as schools and hospitals is identified, and shown to be feasible, resources to undertake it are not made available.

Section 4 will discuss some ways in which the engineering profession can contribute to improved progress in earthquake risk mitigation, both nationally and internationally.

4 What can be done?

4.1 Introduction

In Section 2, I showed that the vast majority of the earthquake deaths which have occurred in the last 50 years have occurred in just a few events, virtually all of them in the developing world. Although some have been caused by landslides, and, in 2004, nearly all of the huge death toll in the Indian Ocean Tsunami was the result of the wave itself, we can say that the collapse of buildings due to ground shaking is by far the largest cause of death and injury. This conclusion is supported by the review of causes of damage in 50 earthquakes by Bird and Bommer (2004). Both masonry and reinforced concrete buildings of the types most commonly found in many earthquake regions have been found to have serious weaknesses, and recently built buildings appear to be no better than the older ones; in fact in several cases the opposite is true.

The second part of the talk reviewed progress over a number of countries, including several of those which have suffered huge earthquake losses over the last half century, and seems to suggest that , in spite of dedicated efforts by a number of administrators and professionals, the situation in many of the most vulnerable countries is hardly improving or is even getting worse. There are new codes for earthquake-resistant construction, and schemes for retrofitting some of the most important buildings. But the mass of ordinary residential construction is hardly affected by these changes.

The most vulnerable countries share several characteristics. They are poor in per-capita income terms (though not necessarily in skills); they are experiencing rapid population growth and at the same time rapid urbanisation. Poverty and urbanisation lead to uncontrolled building in the cities, where the primary concern is to produce living space as cheaply as possible, and in locations determined from employment opportunities; safety concerns (whether for public health or accidents or longer-term matters such as potential earthquakes) are very low on the agenda. The urbanisation of the developing world also has serious consequences for the rural areas and small towns, which are absorbed into the urban industrial economy, often losing their skilled craftsmen who, to support their families, become migrant workers spending most of their lives in distant cities. Thus there is no-one able to maintain those traditions of good building which may have developed over centuries of self-building; and modern, but poor-quality, contractor-built homes become the norm.

What can be done? And what in particular can concerned members of the professional and scientific communities do to help turn the tide and start reducing the catastrophic impact of earthquakes? In spite of this generally pessimistic assessment, there are some positive signs, and some seeds of solutions which can be built on. As the experience of the successful countries has shown, much depends on getting a wide agreement that the problem exists and that it can be tackled.

4.2 The public health perspective

It can be helpful to regard the risks to life and health from earthquakes (and other natural hazards) as a public health issue.

A useful analogy with the recently developing science of disaster mitigation is the implementation of public health measures that began in mid-nineteenth century. Before then tuberculosis, typhoid, cholera, dysentery, smallpox and many other diseases were major causes of death and tended to assume epidemic proportions as the industrial development of cities fuelled increasing concentrations of population. These diseases had a major effect on life expectancy at the time and yet were regarded as unavoidable everyday risks. A recent account of the development of the nineteenth century city in England, (Hunt 2004) gives a stark picture of the situation:

> “The result of these sanitary and housing conditions was a total collapse in life chances. Sickly infants living together in cramped, damp cellars made easy

> pickings. Of the 350,000 deaths in England and Wales in 1842, nearly 140,000 occurred in children under five years old: and those lucky enough to make it beyond the crucial 10-year barrier could not look forward to a much longer existence. In 1841, life-expectancy at birth was 26.6 years in Manchester, 28.1 years in Liverpool and 28 years in Glasgow."

The apparent randomness with which the diseases struck and the unpredictability of epidemics meant that superstition, mythology and a certain amount of fatalism was the only public response to the hazards: the high risk of disease was generally accepted because there was no alternative. As the understanding of what caused diseases increased, chiefly through the efforts of scientists and epidemiologists in nineteenth century, so the incidence of epidemics and illnesses generally became demystified. It became evident that disease was preventable and gradually the concept of public protection against disease became accepted.

It also became evident that sanitation, purification of water supply, garbage disposal and public hygiene were key issues for public health, and politicians and public administrators like Edwin Chadwick campaigned for government action to provide them . The measures necessary to reduce the risk of disease were expensive—massive infrastructural investment was needed to build sewers and clean water supply networks—and required a major change in public practices and attitudes of individuals, but over the second half of nineteenth century, the battle was gradually won. Attitudes changed from the previous fatalism about disease to a public health 'safety culture', where everyone participated in reducing the risk of communal disease.

Public health advances went hand-in-hand with public medicine, medical care, vaccination, primary health care and a health industry that in most countries today consumes a very significant proportion of the nation's and individual family's income. Today, in almost every country in the world, public epidemics are unacceptable. High levels of risk from disease are not tolerated and outbreaks of disease are followed by outbursts of public opinion demanding medical and government response to protect them. Most people now consider it normal to participate in their own protection against health hazards and accept the high levels of cost involved in society's battle against disease. The level of risk from public health hazards that is judged acceptable by modern society is far lower than it was three or four generations ago.

As a result of these changes in attitude, the death rates from the big killer diseases – typhus, smallpox, cholera and other infectious diseases - all fell dramatically through nineteenth and early twentieth century. The continuing widespread application of public health campaigns during the twentieth century has had similar consequences. Figure 8 showed the decline in infectious diseases during the first half of twentieth century in the United States, and the impact of more recent public health campaigns in the developing world, promoted by the World Health Organisation.

The success of the campaign against disease can, according to the US Centre for Disease Control (Centre for Disease Control 1999), be attributed to three separate types of activity. First, to the widespread application of vaccinations and other preventive treatments; second, the development of new treatments for the common killer diseases; and third, to the increasing awareness and self-protection of the population through education and public health campaigns. Earthquake protection campaigns deal with buildings as well as people, and buildings (unlike the human body) differ very widely across the globe. But it seems possible to identify a somewhat analogous set of three principal types of activity which are needed, which can be defined as:

- Wide application of known techniques.
- Development and application of new techniques.
- The creation of a safety culture.

In the following sections, we will look at some of the possible activities needed for earthquake protection under each of these headings.

4.3 Application of known techniques: the lesson of the vernacular

As will be evident from Section 3, a great deal is now known about how to design and build buildings safely in earthquake areas, and how to utilise reinforced concrete, masonry, steel, timber and other materials for this purpose. Virtually every country has its earthquake engineering specialists, and trains engineers in how to use the common engineering materials. And when a disastrous earthquake occurs, they point, despairingly, to the tragedy that so many buildings were built without using this expertise.

It is easy to suggest (and this certainly must be a part of the answer), that more homebuilders must be persuaded to build according to the codes. But there are many good reasons why this may not be the only or the best, solution. So, before rushing to the conclusion that better-built reinforced concrete is the answer, it is worth looking at what other solutions to the problem of building in earthquake areas are available—in particular those that have developed in different parts of the world, in what are called the vernacular building traditions.

It has long been observed (Ambraseys et al. 1975; Davis 1978; Spence and Coburn 1980; Langenbach 2006) that certain tradition forms of building have performed well in earthquakes, and frequently much better than neighbouring buildings built recently using “modern” materials. In earthquakes in Latin America, where heavy adobe buildings have often failed disastrously, buildings built using the timber frame or timber-laced systems known as *quincha* or *bahareque* have survived (Fig. 46). In Indian Kashmir, the braced timber stud-wall construction with brick infill is called *Dhajji Diwari* (Fig. 47), and this has performed well in successive earthquakes (Arya and Chandra 1977; Langenbach 2006). In Turkey, where in successive earthquakes stone and adobe masonry and reinforced concrete have performed badly, the two-storey braced timber frame systems called *himis* and *bagdadi* (with brick and timber infills, respectively) have been observed to be much more earthquake resistant (Fig. 48). Timber based traditional building systems have similarly performed well in Indonesia and Japan (Spence and Coburn 1980).

In the North West Frontier Province of Pakistan the walls of houses were traditionally built of rubble stone masonry, some with thick bearing walls supporting the roofs, others with roofs supported on timber columns independently of the walls. In both cases horizontal timber lacings were used to tie the walls, and the roof construction was similar—closely spaced timber rafters covered with rushes and thick layers of tamped earth. Because of the steepness of the valley sides, houses were terraced, and the use of the roof of one house as the yard of the adjacent house was unavoidable (Figs. 49a,b). Evidence brought back by the UNESCO mission which investigated the damage following the 1974 Pattan earthquake (Ambraseys et al. 1975) indicated that the bearing wall type construction suffered severely, while buildings with roofs supported on timber columns withstood the shaking much better (Figs. 50). Also walls made from angular, cut rocks withstood the shaking better than those from river-worn rounded boulders.

Fig. 46 Bahareque construction in El Salvador, performed relatively well in the 1986 earthquake (Photo courtesy of Randolph Langenbach)

Fig. 47 Dhajji Diwari (timber frame with masonry infill) construction in Indian Kashmir, has performed well in successive earthquakes, including the recent 2005 Kashmir earthquake (Photo courtesy of Randolph Langenbach)

Fig. 48 Traditional Himis construction in Gölcük, Turkey. A survivor of the 1999 Kocaeli earthquake, located in an area where many reinforced concrete frame buildings collapsed (Photo courtesy of Randolph Langenbach)

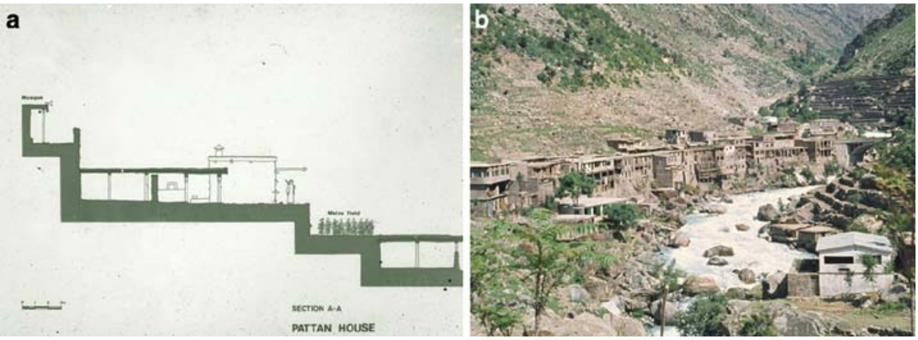


Fig. 49 Traditional dwellings in the Northwest Frontier Province of Pakistan (**a**,**b**) (source (**a**) Courtesy of Andrew Coburn, (**b**) Courtesy of Ian Davis)

This last observation inspired a later study of the housing in the Indus and Yasin Valleys in the 1980 International Karakoram Project (Coburn et al. 1984). If it was found to be true that, without the aid of advanced technology, and using simple techniques and local materials, a viable earthquake resistant system had developed, this could be of global importance, opening the possibility that these techniques could be used in earthquake areas with similar resources elsewhere. It also potentially provided insights into the way that earthquake awareness is developed and passed on in society, and how this awareness, in turn, could lead to modifications in the form and construction of housing.

Fig. 50 Traditional dwelling in North West Frontier Province, Pakistan, with timber-laced walls and independently supported roofs. Survivor of the 1974 Pattan earthquake (Source: Ambraseys et al. 1975)

However, the findings of the Karakoram Project on this subject were not quite as anticipated (Coburn et al. 1984). In most areas where stone was still used, the bearing wall system predominated, and the quality of construction was very poor; few of the houses with independently supported roofs were to be found. And, as the area was opened up for trade through the newly completed Karakoram Highway, a modern system of construction using concrete blocks, sometimes with a concrete frame, was moving in; but without any understanding of the techniques of construction needed for these newer materials. Observations of damage following the 2005 Kashmir earthquake (So 2006) indicated that both concrete block masonry and stone masonry buildings were equally vulnerable; the few traditionally-built survivors did seem to have independent roof support (Figs. 51, 52).

More recently, Langenbach (2006) has been forcefully making the case for the superiority of vernacular forms. Of the comparative performance of RC and *himis* construction in the 1999 Kocaeli earthquake, he writes:

> “The traditional buildings that survived the earthquake were not engineered and lacked steel or concrete. No plans for them were ever inspected because none were ever drawn. They were only rarely constructed by anyone who could remotely be characterized as a professionally trained builder or building designer, nor could most of them be characterized as having been carefully or robustly constructed – although the least damaged among them did meet basic levels of craftsmanship. On the contrary, they were constructed with a minimum of tools with locally acquired materials, using a minimum of costly resources like fuel for the firing of bricks, and they were held together with a minimum of nails and fasteners. Often the timber was not even milled, being only cut and de-barked. It was sometimes nailed together with only a single nail at the joint, and then the interstitial spaces were filled with brick or rubble stone in clay or weak lime mortar. Thus, the traditional buildings possess the kind of deficiencies in construction quality that are identified as reasons why the modern buildings fell down, yet they remained standing. It appears that we have one system constructed with the full benefit of strong materials that is subject to catastrophic failure in large seismic events if it deviates from a sophisticated

Fig. 51 Kashmir earthquake of 2005. Complete failure of concrete block masonry dwellings, Muzaffarabad (Authors photo)

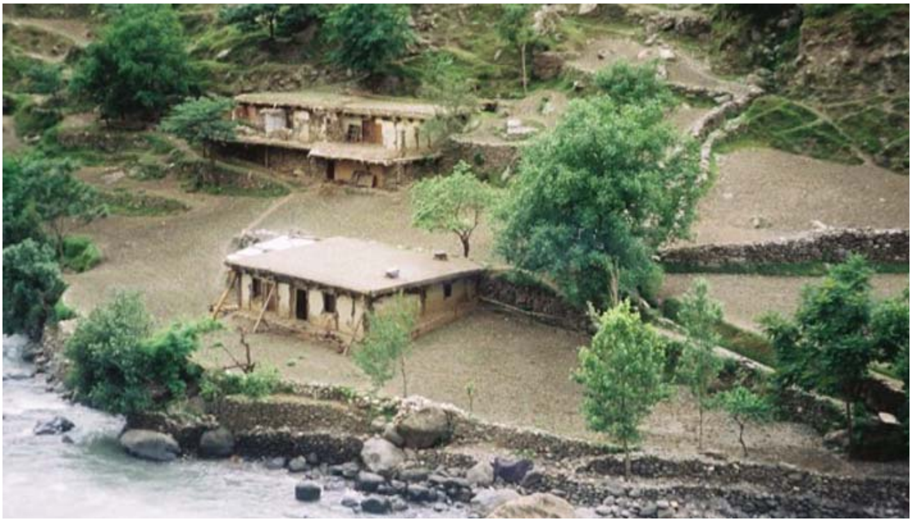


Fig. 52 Traditional masonry dwellings in Kaghan Valley. Survivors of the 2005 Kashmir earthquake (Photo courtesy of Emily So)

> level of design and construction perfection, while we have another constructed of comparatively weak materials by relatively untrained craftsmen that is, with few exceptions, robust enough to withstand major earthquakes."

It is wise to be a little sceptical of the claims for the superior performance of old buildings of vernacular form in earthquakes. The evidence for this is often somewhat anecdotal, and often comes from those with a conservationist viewpoint, already predisposed to admire vernacular forms. More real survey data is needed. Nevertheless there is hard evidence of the superiority of timber framed buildings in Chile: a study based on ten earthquakes between 1918 and 1966 (Joaquin 1966), showed that in locations where 40–50% of adobe and brick masonry buildings collapsed, the collapse rate for timber frame buildings was less than 10%; similarly, the evidence for the better performance of small masonry buildings in general by comparison with reinforced concrete frame buildings in the 1999 earthquake in Turkey is very strong. The Turkish–Japanese survey team in the worst hit town of Gölcük found a 19% collapse rate for RC frame buildings, but only a 4% collapse rate for masonry buildings (Kabeyasawa et al. 2001).

All of this suggests that, while a return to the traditions of hand-made buildings and craft skills passed through the generations may be impossible in most parts of the world today, there is a great deal to be learnt from a study of the vernacular buildings themselves and the way they were built, which would be of immense value in defining appropriate guidance for those who today are considering how to build their houses in known earthquake zones. For the vernacular tradition incorporates a response not just to the distant threat of earthquakes, but also to the climate, the local resources, and the continuing culture of society . Whereas the response immediately following a disaster is likely to overemphasise the earthquake, in the vernacular tradition we can expect to see the earthquake risk in the context of all the physical and cultural constraints which need to be considered in house design (Rapoport 1969).

As Langenbach puts it:

> "when people understand historic structures as being not only archaic and obsolete building systems, but as repositories of generations of thought and knowledge of how to live well on local resources, societies can begin to rediscover the value of these traditions once again by seeing them in a new light – one that at its most fundamental level, can save rather than endanger lives."

Following such observations, over the last 20 years, we have seen the beginning of an alternative form of earthquake engineering which, rather than seeking to impose a new earthquake-resistant design concept, starts with the way that people build traditionally, and looks for ways to improve the earthquake resistance of their dwellings without radically altering the form of the house. Such "building for safety" projects will be considered in the next section.

4.4 Building for Safety

There is a long tradition among engineers of preparing and circulating illustrated guidelines for the reconstruction of small buildings following an earthquake disaster. This is a familiar activity to the engineering profession, an adaptation, at a level perceived as appropriate to the individual householder and small builder, of the process of writing earthquake design codes. Some of the first such guidelines were prepared in India (Arya 1981), and they contain much good advice. Many other booklets and guidance documents have followed (Coburn et al. 1995; Patel et al. 2001; ERRA 2006), (Fig. 53a,b, Fig. 54). There are two major problems to be overcome: first, they tend to emphasise the incorporation of earthquake-resistance above all else, and often do not consider issues such as traditional notions of the subdivision of internal space, or the provision of insulation or smoke extraction. Rebuilding in a way which does not take all aspects of the occupants' health and safety into account is likely to be counter-productive: it may even lead to more deaths in the long-run than are saved in future earthquakes. Second, their illustrations are often based on assumptions about how people read pictures which may be wrong. Dudley showed (Coburn et al. 1991) that in showing good and bad ways to reinforce a concrete ring-beam, the use of a tick and a cross, and other drawing conventions, were not understood by builders in Northern Pakistan (Fig. 55a,b). It is clear that the design of educational materials intended for small builders needs to be carefully tested to make sure that they communicate the message they are intended to. This is another lesson which can be learned from public health campaigns, where such testing is considered essential (Dudley and Haaland 1993).

Most crucially, though, there is little possibility that the guidance contained in printed documents or manuals will be widely adopted unless they are accompanied by builder training and other promotional work designed to communicate both the awareness and the skills more directly. Cuny (1983) in his classic work Disasters and Development distinguishes *passive* and *active* mitigation. Passive mitigation is the development and application of measures such as building codes, land use, zoning, and planning techniques to reduce vulnerability. Active mitigation encompasses those activities which require direct contact with the people, and include public education, the introduction of modification techniques, the initiation of housing improvement programmes and so on. And he states:

> " In practice passive activities have little impact on reducing vulnerability in the Third World; for the most part zoning and building codes are unenforceable"

There are today available to us a number of good models of such active mitigation programmes, or building for safety programmes. Following the disastrous Yemen earthquake of December 1982, Jolyon Leslie set up the Dhamar Building Education

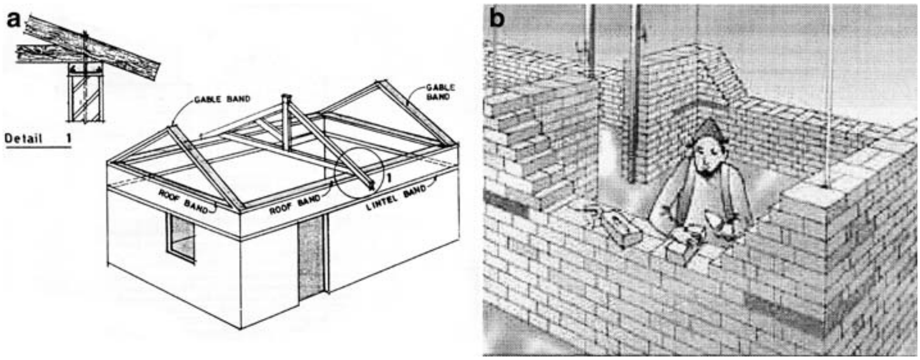
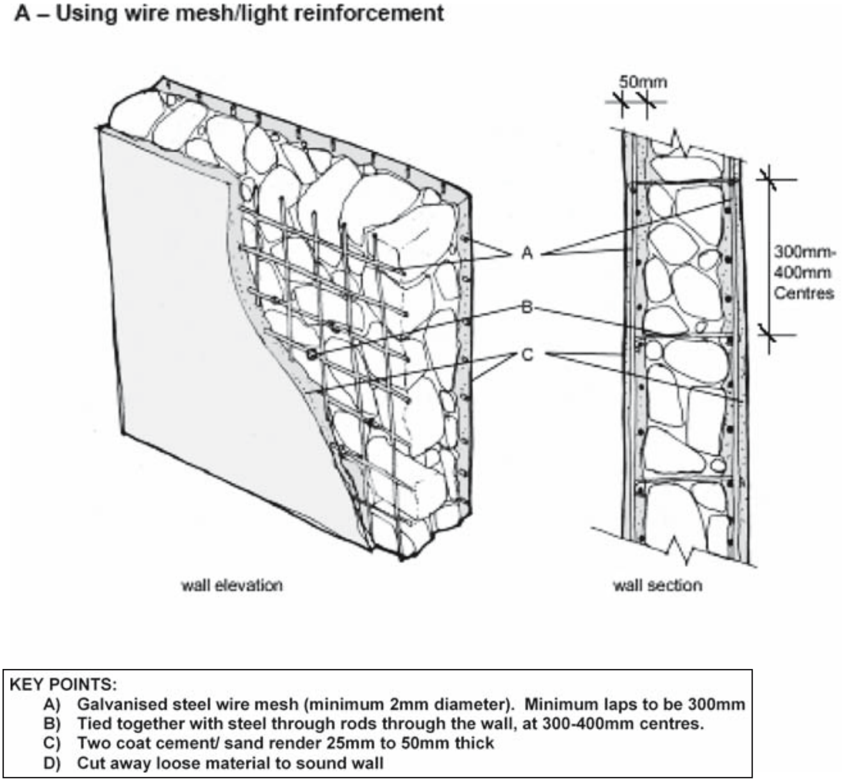


Fig. 53 Diagrams from manuals for earthquake-resistant construction of masonry buildings. (**a**) From India in 1981(Source: Arya 1981); (**b**) from Pakistan in 2006 (Source: ERRA 2006)


A – Using wire mesh/light reinforcement

KEY POINTS:
A) Galvanised steel wire mesh (minimum 2mm diameter). Minimum laps to be 300mm
B) Tied together with steel through rods through the wall, at 300-400mm centres.
C) Two coat cement/ sand render 25mm to 50mm thick
D) Cut away loose material to sound wall

Fig. 54 The GREAT manual for repair and strengthening of earthquake-damaged Masonry, Gujarat, 2001 (Patel et al. 2001)

Project, which continued for the next 3 years, with support from OXFAM. The aim was "to encourage self-reliance of builders, while reviving confidence in traditional techniques, and maintaining continuity of building practice" (Leslie 1984). The earthquake caused widespread damage and destruction in an area where the traditional form of construction is of rubble stone (Fig. 56a, b). Rural as well as urban houses are often two or more storeys high, with walls of rubble or dressed stone and timber floors and heavy flat timber roofs. The builder training programme was aimed at local builders, with the intention of introducing some simple techniques for strengthening houses, using locally available materials and skills (Leslie 1984).

In this part of the Yemen, the principal causes of weakness in traditionally constructed dwellings were found to be at the wall-to-wall junctions, where separation occurred, and at the junctions of walls and roofs, where the timber joists separated from their supporting walls, and in the separation and disintegration of the masonry walls themselves, due to inadequate bonding. The training programme emphasised single storey building, and demonstrated techniques (such as better mortar, stone dressing and through-bonding) for constructing a wall with better integrity and earthquake resistance. It also offered a range of techniques for both strengthening the corners and providing a ring-beam to connect the tops of the walls and the roof (Fig. 56b). Over a period of 4 years over 1,000 builders were trained, about 25% of the total

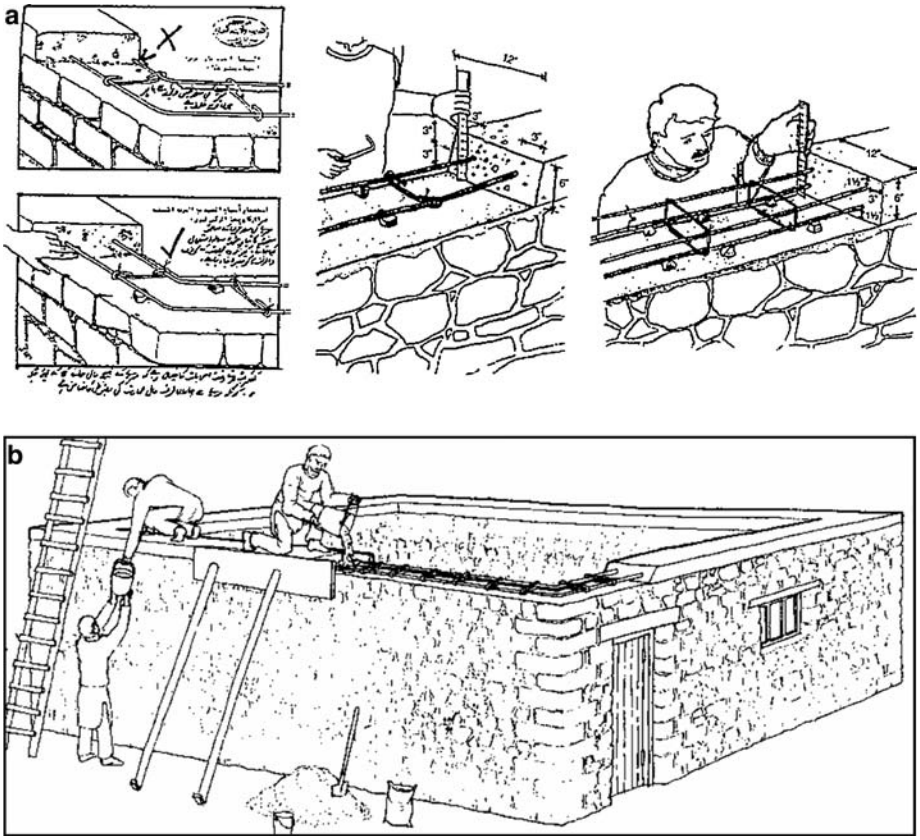


Fig. 55 Normal drawing conventions (like a tick and a cross) may not communicate the intended message to rural builders. (**a**) A more realistic image of the intended technique may be needed. (**b**) The way the manuals are understood needs to be carefully researched (Source: (**a**) Courtesy of Jolyon Leslie, (**b**) Courtesy of Eric Dudley)

number of builders in the area, and most were found (in a subsequent study) to have changed their practices as a result of the course (Leslie and Coburn 1985).

John Norton, an architect, who, with Development Workshop has devoted much of his professional life to such builder training programmes (Figs. 57a,b), has established a set of principles (Norton 1976). Training programmes should in his view:

- Develop from existing typologies, materials and technologies rather than replace them.
- Aim to communicate with existing local builders, and learn from/enhance their existing skills.
- Make use of the skills of professionals in devising technical options for upgrading and preparing training materials.
- Build up capacity of local organisations for disaster mitigation.

Eric Dudley, also an architect was working on development projects in the Andean highlands of Ecuador in March 1987 when a major earthquake struck the area. Concerned by the failure of so much technical aid in the past to be adopted by the rural

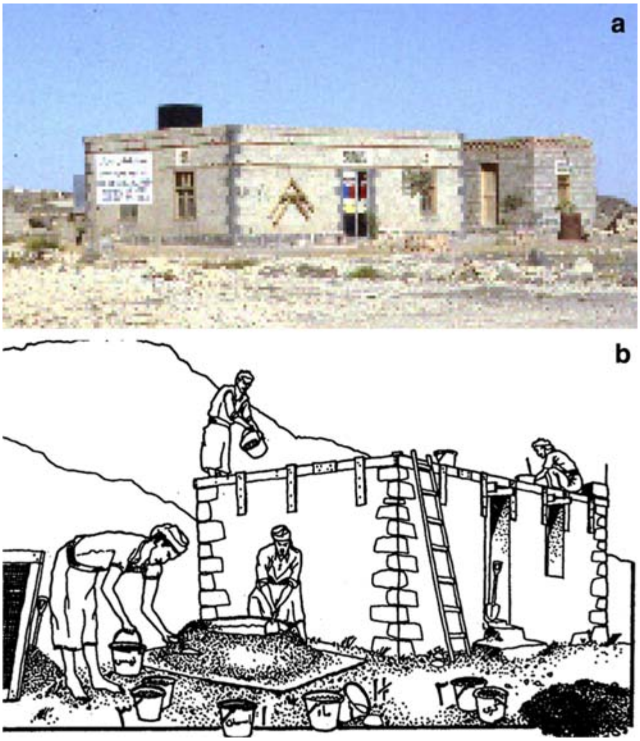


Fig. 56 The OXFAM Dhamar Builder Education Project, 1982-1984. The aim was "to encourage self-reliance of builders, while reviving confidence in traditional techniques, and maintaining continuity of building practice" (**a**) Photo courtesy of Andrew Coburn, (**b**) Source: Leslie 1984)

community, he proposed (Dudley 1993) a set of three criteria against which people everywhere assess new ideas, and suggested that these should be used to evaluate technical aid for rural communities:

- Does it make sense? Is the idea *reasonable* in terms of the intended beneficiary's own rationale?
- What is it? Can the idea be *recognised*—does it have a name and are its limits clearly defined?
- Is is worthy of me? Is the idea *respectable*—is it something which people like us do?

Guided by these principles (the three r's of technical aid) Dudley developed an approach to rebuilding the village houses, largely of rammed earth walls, which involved, among other improvements, improving the corner detail through the use of a new corner mould (Figs. 58a,b). Although the modifications were cheap, buildings rebuilt with this corner mould were instantly recognisable, and this was seen as a big factor in the successful adoption of the technology.

Rajendra Desai is an engineer turned development worker, who has developed a similar approach to post-disaster reconstruction in India. Following the Latur district earthquake in 1993, his Ahmedabad Study and Action Group (ASAG) developed a set of modifications to the traditional rural housing technology, which used a roof

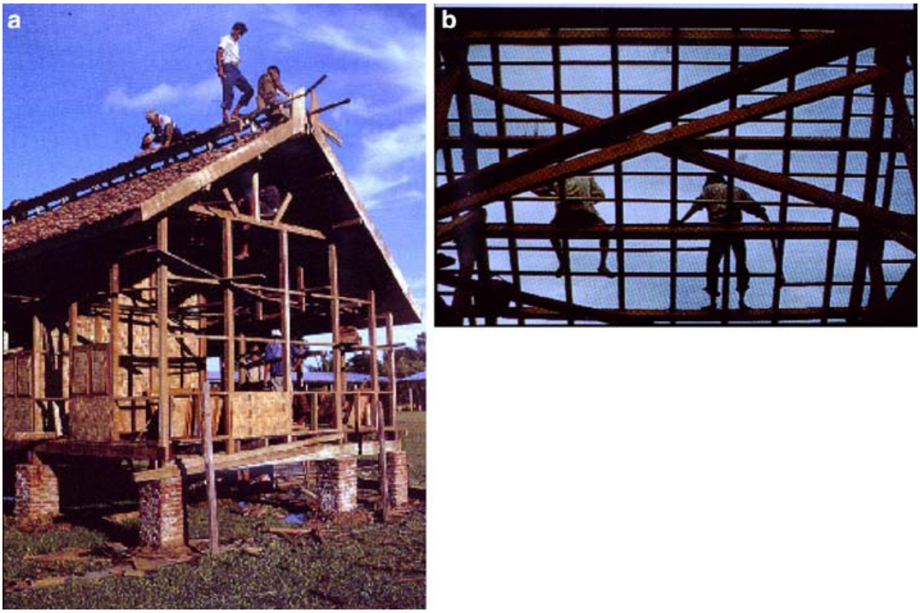


Fig. 57 Builder education programmes in construction (a) Architect training in Laos, Photo: courtesy of John Norton (b) Builder training in typhoon-resistant housing Vietnam, Photo: courtesy of Development Workshop

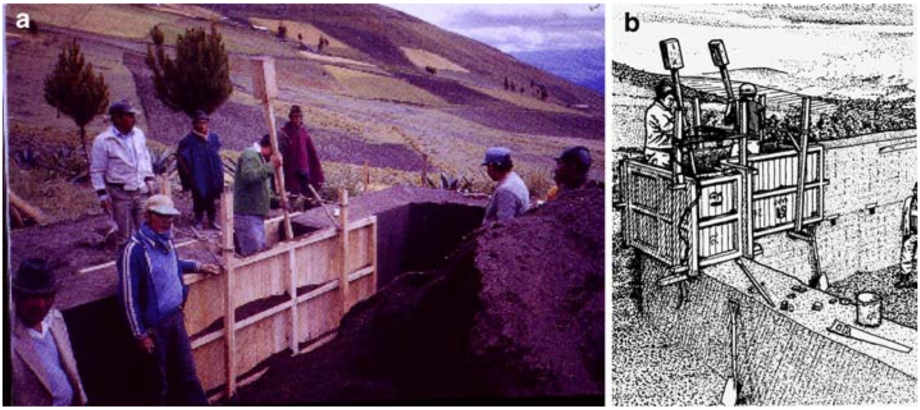


Fig. 58 Builder education in the Ecuadorian Andes, in rebuilding after the earthquake of March 1987 (**a**). Reconstruction used traditional rammed earth wall construction but with an improved mould which helped to eliminate a critical weakness at the corners (**b**) (Photo and drawing courtesy of Eric Dudley)

independently supported by timber columns (ASAG 1996). This became the basis of a builder training programme, as a result of which it was widely adopted. Following the 2001 Gujarat earthquake, Desai, working through the National Centre for People's Action in Disaster Preparedness, and SEEDS, organised training programmes for local builders from throughout the state in a training programme which involved

Fig. 59 OXFAM/World Neighbours Rebuilding Programme after the 1976 Guatemala earthquake used a timber frame infilled with locally made concrete blocks (**a,b**) (Photos from OXFAM Guatemala)

training both homeowners and masons and incorporated a shake-table test rig to demonstrate the benefit of improved techniques (Murty et al. 2005).

Other similar builder training programmes have taken place in Guatemala in 1976 (Figs. 59a,b), the Alto Mayo region of Peru (Schilderman 2004) after the 1990 earthquake there, in the Katchchh district of Gujarat after the 2001 Bhuj earthquake (Patel et al. 2001), (Fig. 54) and in Indonesia and Thailand following the 2004 tsunami. These are some examples of an approach which, if widely replicated, might have the potential to make a serious difference to death tolls from future earthquakes. Of the buildings upgraded in the programmes described only those in Peru have been tested in a subsequent earthquake. But there is evidence that similar programmes elsewhere, not widely reported, may have begun to have an impact. For example, in the Bantul District of Java, devastated by an earthquake in May 2006 in which 6,000 died, one survivor attributed the survival of her brick masonry house to the "steel bars" which had been installed when it was built a decade ago (The Observer 2006). Of course, the occurrence of an earthquake creates a "window of opportunity" for change, and all of the programmes described have been set up in the context of post-earthquake reconstruction. It will be vital, but much harder, to spread the same ideas about good, or safe, building to the adjacent areas, not recently damaged in an earthquake, but possibly, just for that reason, even more at risk. In Indonesia for example, though rebuilding in the devastated Aceh Province is certainly taking the tsunami risk seriously, it is the communities to the south of Aceh Province which are in fact more likely to be tested by a large tsunami in the near future, and it is in these communities where better awareness, and better building, are most needed.

All of the programmes described involved trained building professionals, architects as well as engineers. But in confronting problems of low-cost housing, rural builders and development issues, they are working well outside the normal sphere of their professional competence, and using, or developing, skills and understanding which they will hardly have begun to think about in their professional formation. Yet clearly the improvement of living and housing standards among those most vulnerable to disaster is a vital task for the engineering and architecture professions. Structures need to be put in place—through national governments, NGOs and UN Agencies—in which technical support for small-scale building projects is seen as a normal part of professional activity. The architect Hassan Fathy, in Egypt, faced this problem long ago, and wrote (Fathy 1973):

> “Unfortunately the training provided in our architecture schools today does not even begin to help the architect who tackles rural problems. This training is aimed at the needs of the towns.. and completely ignores the needs of the countryside… But because of this academic indifference, there is an altogether too lighthearted attitude to the very grave business of remodelling our villages”.

Today we have a number of NGO’s such as RedR (Register of Engineers for Disaster Relief) and ASF (Architectes Sans Frontières) who are working hard to make up for these deficiencies in formal education, but much more is needed.

4.5 The problem of the burgeoning cities: building control

The experience of recent earthquakes, especially those in Turkey and Taiwan (1999) and Gujarat (2001), has demonstrated that even when carefully formulated codes of practice for construction exist, widespread failure of apparently engineered buildings often occurs (Figs. 60, 61). Usually the press and the public attack the builders as the guilty party, with some justification, but in reality the inadequate standard of construction is the result of a more extensive inadequacy of building control involving not just the builders, but government, the building design professions, the property developers and eventual owners, the builders and also the eventual occupants.

According to Jain (2006) addressing the problem in India:

Figs. 60, 61 Collapses of recently constructed reinforced concrete buildings like these in Turkey (1999) (Fig. 60, this page) and India (2001) (Fig. 61, next page) point to a lack of control over the planning design and construction process (Photos: Fig. 60 courtesy of Randolph Langenbach, Fig. 61: author’s photo)

Fig. 61 See Fig. 60

> "The 2001 Bhuj earthquake was the first time the Indian middle class saw multistory buildings fall like a pack of cards, and realized that these housing types are similar to the ones in which they are living or have plans to retire into. The Central and State governments made numerous announcements and many activities were started for earthquake safety. It was hoped that India would perhaps now be able to set up a strong programme for earthquake safety and that in future most (if not all) new constructions would comply with seismic codes. Unfortunately, five years after the tragic earthquake, not even one major city in the country has an effective system to ensure that all new constructions fulfill seismic requirements and we continue to build unsafe constructions"

A study of the causes of poor quality construction in Turkey (Gülkan et al. 1999) pointed to deficiencies in both the nature and implementation of laws and regulations concerning the planning system, the project supervision at the design stage, and the system of supervision on site. Most crucial were the deficiencies in building construction supervision, which made no requirement for adequate expertise on the part of the supervising engineer, or for the supervising engineer to have any involvement with the process on site; a lack of personal liability insurance on supervisors; and no mechanisms for municipalities to demolish unpermitted buildings or to prosecute negligent builders.

Since 1999, serious efforts have been made to overcome these deficiencies in Turkey through new legislation and through setting up new training programmes. One particular innovation proposed, of general importance, was the establishment of a new role of building supervision specialist. It was proposed that private building supervision firms would to be offered, and paid for, the responsibility for supervision of building projects, both in the design and construction phases; and that that responsibility would carry with it the liability for offsetting any losses which might occur to the owner, during 10 years, resulting from poor construction. This liability would be backed by indemnity insurance on the part of the supervising firm. This measure in effect would move from the municipalities to the private sector the task of building control which they had failed (or been unable) to undertake adequately. These proposals were incorporated in a Decree brought into effect soon after the 1999 earthquake. The enforcement of this decree was initiated in 27 pilot provinces, including all those affected by the 1999 earthquakes, but later withdrawn.

In India, Jain (2006) has proposed that municipal authorities should be required not only to collect a certificate of compliance of seismic codes for the new buildings, but also to verify such certificates independently by a cursory review of structural design and drawings. Nevertheless he notes that officials are reluctant to take on this additional responsibility, except in the towns most affected by the 2001 earthquake (Bhuj, Anjar, Rapar, Gandhidham, and Bachau) which had implemented a system wherein building permissions will be given by the town planner only after receiving clearance from an engineer who would review the structural features for seismic code compliance.

What appears to be vital is that, in every country, a proper system of licensing engineers is put in place so that those who have responsibility for all buildings are competent to do so; and that engineers are held to be liable for the performance of their buildings in earthquakes, which means, among other things, that they will have to take some responsibility for seeing that what happens on site is in accordance with their design. This is partly a matter for government, but professional engineering bodies in all earthquake countries need to be involved in defining the appropriate laws and campaigning to have them passed into statute.

An alternative solution might be to abandon entirely a system of construction which depends so much on the quality of construction, and can so easily be defective and a prey to corruption. But this is not a realistic or viable solution. Reinforced concrete is today the material for the construction of permanent dwellings in virtually all the rapidly growing cities of the world. There is no realistic alternative in sight. The engineering profession must get alongside national governments and municipal authorities to see that effective building control systems and code enforcement are put into place. The present struggles to achieve this in Turkey and India reported briefly above contain important lessons for other countries facing similar building control problems..

4.6 Harnessing new technology

The tremendous advances in the technology of earthquake engineering over the last half century have unfortunately made little impact on the way in which the dwellings and workplaces of most of the world's population are built. Active and passive control systems, base isolation, new materials and new techniques for design are neither designed for, or affordable by, those who currently are most vulnerable to earthquakes. Few papers in 13 World Conferences on earthquake engineering have addressed the problem of finding and demonstrating low-cost techniques suitable for upgrading low-strength masonry or poor-quality reinforced concrete. But this may be beginning to change. There have been a number of studies which have looked specifically at the building technology used in the most earthquake-prone countries, and have proposed ways to upgrade them at minimal cost.

The aim of the project on Reducing Earthquake Losses in Rural Areas carried out by the Martin Centre at Cambridge University and Middle East Technical University (1982–1985) was to find ways to help villagers in the highly earthquake prone regions of Eastern Anatolia to build more earthquake-resistant houses at low cost . It involved a field study to look at current techniques, post-earthquake damage surveys to look at the mechanisms of damage, the development of alternative proposals (Fig. 62a,b), the testing of these on a purpose-built 20 m^2 impulse table, and an economic assessment of the benefits of a strengthening programme (Spence and Coburn 1987a,b). The new technique involves the reintroduction of a once-common technique of lateral reinforcement of the rubble stone masonry walls using timber lacing (*hatils*), and an alternative concrete *hatil* system. (Fig. 63a,b).

A research programme with similar objectives has been in progress at the Catholic University of Peru for three decades (Blondet et al. 2006). Aimed at developing appropriate low-cost techniques for upgrading the adobe masonry houses of Peru which are highly vulnerable to earthquakes, a range of different upgrading techniques has been developed and tested. Earlier studies used natural materials such as cane and timber, and alternatively wire mesh: however, the natural materials proved scarce, and the industrial mesh too expensive to find a wide application. Recent studies have focussed on the use of polymer meshes, including a very cheap material widely used for soft fencing (Fig. 64a); and shaking table tests have demonstrated that even the cheapest of these materials, applied externally and tied through the walls, is able to prevent collapse of typical adobe structures in a major earthquake (Blondet et al. 2006). It is a potential life-saver on a large scale, either as a retrofit or in application to newly built buildings.

Over the last 2 years, researchers at the International Centre for Urban Safety Engineering at Tokyo University have turned their attention to the problem of improving weak masonry structures (Mayorca et al. 2006). A review of masonry styles and their damage mechanisms, and of alternative masonry retrofit techniques, led to the conclusion that a new, cheaper material of wide availability was needed. Subsequent research has focussed on the application of polypropylene bands as used universally for packaging. A technique for forming these bands into a mesh and then wrapping the mesh around a wall using wire connectors has been developed (Fig. 64a). Extensive laboratory testing of the technique has been carried out, to prove its viability, and this has been accompanied by the development of appropriate numerical techniques for modelling the performance of the composite material. Further phases of the work planned involve the development of guidelines for the application of the method, and an educational programme to ensure implementation: a recent demonstration has been carried out in Pakistan.

An interesting variant on the idea of reinforcement of low-strength masonry with strips of high performance manufactured materials has been proposed at Victoria University Wellington (Charleson 2006). This proposes the use of reinforced strips cut from used car tyres as a cheap reinforcement for adobe and rubble stone masonry. By cutting strips on a spiral, a strong strip of 5 m length can be cut from a single tyre. These can be laid horizontally in the wall to improve in-plane and out-of-plane resistance, and also be used for vertical reinforcement. They can also be used for local confinement (Fig. 65). The system was tested under static lateral loads and shown to lead to a huge increase in resistance; an economic model is also proposed, to assess the cost of implementation of such a scheme. Development of this scheme, alongside researchers at IIT Kanpur, in India, is in its infancy, but it deserves to be taken further.

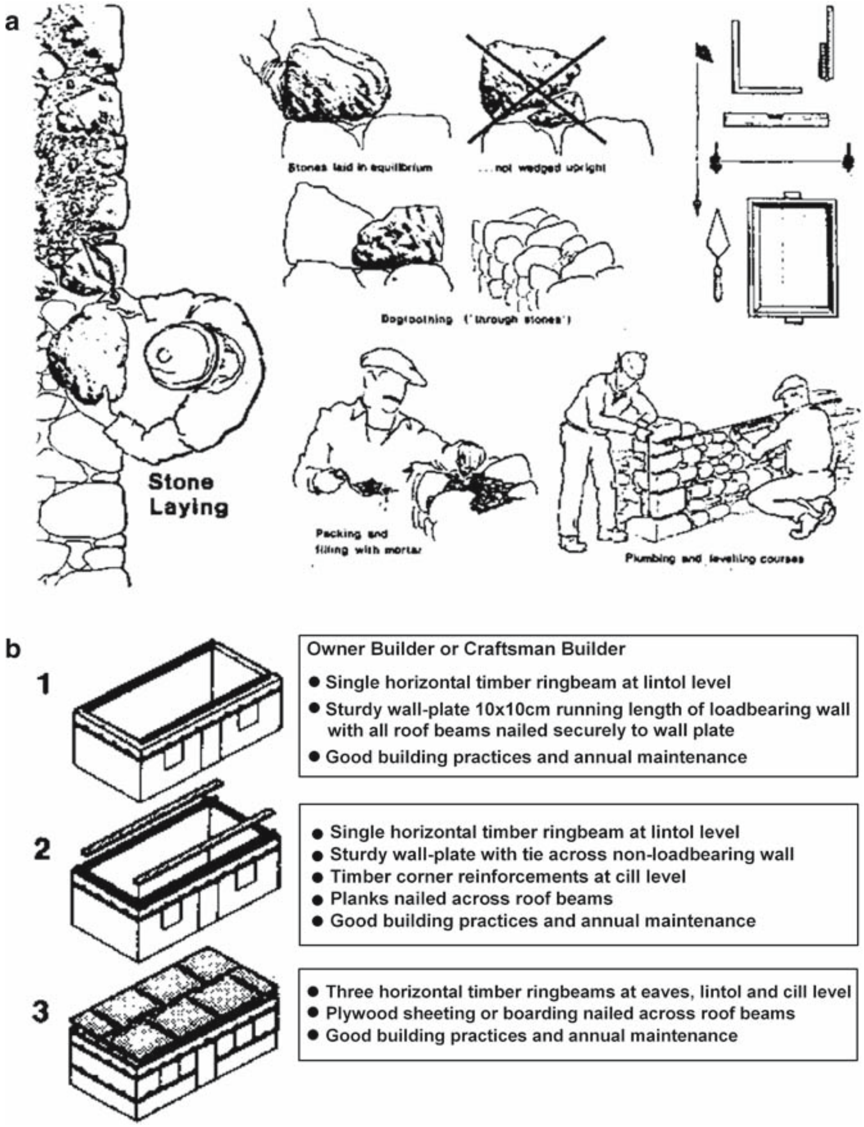


Fig. 62 No-cost (**a**) and low-cost (**b**) improvement measures proposed for stone masonry construction in Eastern Turkey (Drawing courtesy of Andrew Coburn)

Several other similar research projects on low-cost building, strengthening or retrofitting of ordinary structures have been reported recently (e.g. Costa 2006). With all such studies, the problem is how to achieve application by the intended beneficiaries, the urban and rural house-builders. This is a problem even when technical innovations are intended for use by highly educated designers working in a modern industry. It is far greater when they are intended to be adopted by individuals in the building of their own houses, who are not easily reached by any formal rules or guidance documents and are likely to be reluctant to pay for strengthening against a threat that may or may not materialise within the next few decades. Massive builder training and educational

Fig. 63 Low cost impact table designed for full-scale testing of improvements to stone masonry construction (**a,b**) (Photos by author)

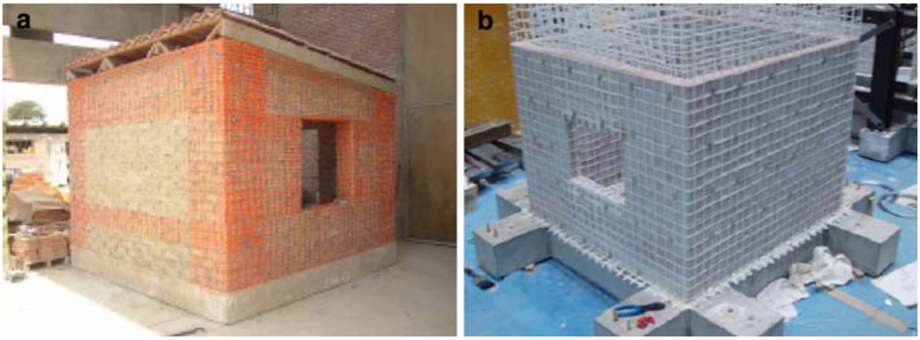


Fig. 64 Development of new low-cost materials for strengthening weak masonry buildings (**a**). At the Catholic University of Peru, a technique using soft fencing has been used; at the University of Tokyo, a mesh of polypropylene packaging bands is proposed (**b**). (Source: (**a**) Courtesy of Marcial Blondet, (**b**) Courtesy of Kimiro Meguro)

programmes will be needed, of the kind which today happen only during the reconstruction programme after a major earthquake. The community-based approaches developed by Practical Action, described by Schilderman (2004), are a model of such activity, in which it is essential for engineers and architects to become involved.

Perhaps the best that can perhaps be hoped for initially, is adoption in a few pilot projects; if in the event of an earthquake, the reinforced houses are seen to have performed better than the others, the technology may spread under its own momentum, as has begun to happen with the improved *quincha* houses in the Alto Mayo region in Peru (Schilderman 2004).

4.7 Creating a safety culture

The creation of a safety culture in an earthquake zone potentially encompasses a great range of different activities, and engages all individuals and groups in society. It includes personal risk management, the responsibility of employers to their staff, the responsibility of local government for creating safe cities, and national governments

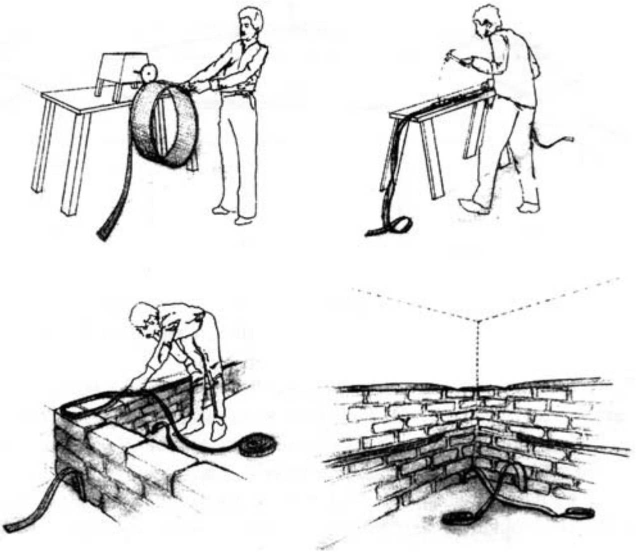


Fig. 65 The use of waste car tyres for reinforcement of low-strength masonry (Drawing courtesy of Matthew French)

for creating the appropriate structures. None of the mitigation actions which the engineering and scientific community identifies as being needed are likely to succeed without prior efforts to promote, at all levels of society, an awareness of the potential threat from earthquakes, and the belief that something can be done about it. Section 3 of this paper has identified some societies which have been successful in creating a safety culture, others which have not. This section will attempt to identify a few of the specific ways in which the scientific and engineering community can be and have been active in the creation of a safety culture, through in particular:

- Education and outreach programmes.
- Public advocacy for new legislation.
- Prioritising action for retrofitting schools.
- Developing earthquake insurance schemes.

I hope to show that, although these activities are apparently somewhat outside the normal professional and academic activity of engineers and scientists, their involvement is nevertheless crucial to the success which has been achieved.

4.8 Education and outreach

In most parts of the world, damaging earthquakes occur only infrequently, with recurrence intervals of half a century or more; and in this situation public awareness of the earthquake risk is likely to be very low. This makes it essential for the scientific and engineering community, who have a better understanding of the hazard and of the possible impact of a major, foreseeable event, to become involved in activities to raise public awareness. This can involve education and outreach at all levels, from schoolchildren, through builders and property-owners to business and political leaders, and many kinds of events can be used.

Some good models exist in some of the highest risk countries. In 1997 GeoHazards International, a California-based NGO, got together with the National Society

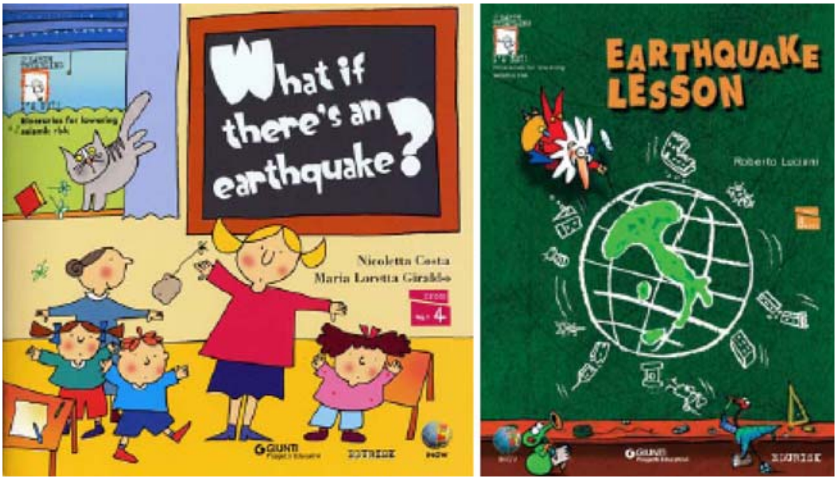


Fig. 66 Educational tools developed by the EU-funded Edurisk Project (Courtesy of Romano Camassi)

for Earthquake Technology—Nepal, NSET, a local NGO with funding from USAID to set up the Kathmandu Earthquake Risk Management Project (Dixit et al. 2000). The Kathmandu Valley has had major earthquakes in the past, but the last was in 1934; and since that time the population has grown enormously and building has been uncontrolled with no effective application of the building code. At the start of the project public awareness was low, and an important early component of the project was to develop an earthquake scenario, showing the losses that would occur if the 1934 earthquake recurred. The results were published in a leaflet which was widely distributed, with a view to providing emotional understanding of the earthquake phenomenon. Among other activities used to raise awareness was the designation of 15 January, the date of the 1934 earthquake, as Earthquake Safety Day with a range of associated events.

India has a similar problem of large earthquakes with long recurrence intervals. Following the 2001 Bhuj earthquake, IIT Kanpur set up the National Information Centre for Earthquake Engineering (NICEE 2006), with the aim of maintaining and disseminating information related to earthquake engineering throughout India, with a particular focus on academic and professionals, among whom awareness was found to be very low. Workshops and distance-learning are used, and in 2006 its list of eMail subscribers reached 3,600 (www.nicee.org). Also in India, the Girl's Polytechnic in Guwahati, Assam, has been conducting an awareness campaign among the most disadvantaged members of society, the tea-garden labourers; among the range of activities were street plays in which earthquake-awareness is presented in new scripts around the ancient legends of the Mahabarata (Barooah 2006).

At the 2006 European Conference on Earthquake Engineering, a special session was held on Education and Outreach for Risk Reduction, and encouraging examples of education projects were reported from Egypt, Mexico, Italy, France, Slovenia and Greece, as well as from India, (Barooah 2006), and Italy (Brasini et al. 2006), Fig. 66.

Fig. 67 Art work done by children in British Colombia, Canada for an earthquake awareness project (Courtesy of Tracy Monk)

4.9 Public advocacy for new legislation

In democratic societies, the road to the introduction of new legislation to reduce earthquake risks can be long and tough, and involve not only convincing legislatures with other priorities, but also facing down resistance from groups who do not want to be burdened with the extra costs or resources it will involve. Most of the reported achievements (Olshansky 2005; Ohlsen 2003; Monk 2006) come from the countries identified as "success stories" in Section 3. Out of these experiences, Olshansky has derived a set of principles for action (Olshansky 2005):

- Be persistent, yet patient.
- Have a clear message.
- Understand the big picture.
- Work with others.

The scientific and technical component is apparently only a small part of this, but it is absolutely crucial, since resistance will need to be overcome; so the scientific and technical community must play a central part in these advocacy activities.

The European Association for Earthquake Engineering has, among its objectives "to play an active role in all aspects of mitigation of the effects of earthquakes in Europe and to set a model for other national, regional and international organisations to follow in advancing earthquake risk mitigation". Efforts to realise this objective have to date mainly concentrated on the European Commission and the European Parliament. Following the disastrous failure of a school in the Molise earthquake in 2002, (Fig. 43) a question, drafted in consultation with members of EAEE, was presented to the European Parliament requesting the Commission to "formulate a Directive requiring the Member States to establish programmes of assessment…of all buildings and structures in areas known to be prone to damaging earthquakes and of strengthening the ones which are found to be inadequate". The answer was discouragingly negative, but it is perhaps not surprising that the European Commission would not favour the idea of regulation on this issue at the European level. Today the EC tends to prefer other kinds of incentives rather than regulation; and the principle of *subsidiarity* makes the Commission reluctant to initiate action in any matter in which effective action can be taken by member states individually. However, it seems clear that one of the reasons for inaction, both at the European and national level, is lack of awareness of the scale of the problem and of its potential solutions, on the part of the EC's officials and the European Parliamentarians. The EAEE accordingly has formulated a strategy for a multi-agency involvement by the EU in earthquake risk reduction (Soebce et ak. 2007), and this will be launched at an information meeting in Brussels early in 2007.

4.10 Prioritising schools

On any society's safety agenda, the safety of school children must have a high priority. Yet public school buildings have collapsed very regularly in earthquakes, even in cases where most other buildings have survived, and many school children have been killed. Italy's Molise earthquake was such case, but children seem to have been disproportionately at risk in other events, such as Armenia (1988), Bingöl, Turkey (2003), and most recently in Kashmir (2005), where numerous government built schools collapsed, killing many thousands. Any many more school children have been spared only because their school collapsed outside school hours.

There is clearly a need for engineering intervention, beginning with assessment of all schools in earthquake-prone areas, identifying those at risk, and then either demolishing and replacing or strengthening those found to be inadequate. Much good recent research on these topics has been done (Grant et al. 2007; Dolce 2004; Penelis 2001, etc.). But in order to create the conditions for such programmes to take place, efforts are needed to highlight and quantify the problem, bring it to the top of the action agenda of the responsible agency, and of politicians, and ensure that the funds are made available. Engineers and seismologists also have a crucial role to play in these formative stages.

In the Kathmandu Valley Earthquake Risk Management Project (Dixit et al. 2000), a simplified school vulnerability assessment was a high priority; it was investigated through a questionnaire filled in by head teachers, through visits by engineers and through seminars to raise awareness of earthquake risk. A model retrofit scheme was carried out, and others have followed (see Sect. 3.6).

A more ambitious initiative on school safety was launched in 2004 by the Programme for Educational of Buildings of OECD (Organisation for Economic Cooperation and Development), working with GeoHazards International. An Expert Group of engineers and public administrators met in Paris, and were, over 2 days, guided towards the formulation of a set of proposals on school strengthening, which were later formulated into a Recommendation. This Recommendation, which, once adopted, has a legal status in OECD countries, asks all countries to ensure that mandatory programmes of school seismic safety are in place in OECD and Partner countries, gives a set of guiding principles and describes their components (Yelland and Tucker 2004). The Recommendation was adopted by the OECD in July 2005, and is in the early stages of implementation in a number of countries. A similar initiative, using the same set of principles, is being considered by the OCE, a sister economic cooperation body including Turkey, Iran, Pakistan, Afghanistan and several Central Asian republics. Meanwhile, within Europe, school assessment programmes are happening in Italy, Greece and France.

In the Canadian Province of British Colombia, an organisation called Families for School Seismic Safety (FSSS) was set up through the initiative of a Vancouver family doctor, who found that her children' school was amongst many public schools at risk of collapse in a foreseeable earthquake (Monk 2006). FSSS allied itself with the local engineering community, and used lobbyists to bring the issue into the public arena at the time of Provincial elections, asking candidates to pledge, if re-elected, support for a programme of action to reduce the risk. The highly successful campaign (Fig. 60), used a public health argument, and successfully argued that funds for this public health programme should not have to compete with other projects for a slice of the education budget. In November 2004, the State Premier made a $1.5 billion commitment to getting all schools upgraded in 15 years. According to Monk (2006), the role of engineers in such actions is to:

- Create simple information.
- Educate the population, including media releases and events.
- Encourage community awareness and build a culture of prevention.
- Talk about the costs and consequences in human terms as well as infrastructure terms.
- Strengthen the case with the parallel collection of data in human terms—so that costs and benefits can be calculated and the effectiveness of this intervention compared to others.
- Show that compared to many routinely employed medical interventions, mitigation can be far more effective.
- Claim and quantify the successes (not the luck).

4.11 Insurance and earthquake risk mitigation

Earthquake insurance is still in its infancy: at the present time even in many advanced countries, earthquake insurance take-up is not high, and recent schemes for compulsory insurance of residential buildings (e.g. in Turkey and Algeria) have struggled, as noted in Section 3. But a soundly based earthquake insurance scheme is a key component of the creation of a safety culture, because it encourages the owners of property to understand the risks they face. It is a well-established practice in many types of insurance that the premium paid is lower if the insured can show that various protection measures have been taken—locks and alarm systems for theft insurance, and smoke alarms for fire insurance, for example—and the same approach could in principle be, and is in a few cases, applied to earthquake insurance. A survey of various national insurance schemes (Spence 2004) found that methods adopted have included:

- Relating the premium to the risk level of the building, for example considering the earthquake zone it is located in or the construction type or materials.

- Offering a discount on the premium if the building has undergone structural mitigation (i.e. retrofit).
- Enforcing minimum non-structural measures that must be met before insurance can be taken out.
- Offering insurance cover that will pay the cost of bringing the building into compliance with building standards during repair or rebuilding of the building after substantial damage.
- Invalidating insurance if a building is altered contrary to the related design or in a way that will detrimentally affect the load-bearing system.
- Funding research into mitigation and supporting public education.

However, none of these various approaches is yet in general use. This is partly because of the difficulty of ensuring, for each of many thousands of properties at risk, that the measures have been taken, but also partly because of the difficulty in estimating the reduction in risk which would result from any particular measure. It remains a challenge for earthquake engineering to develop reliable methods to estimate the risk reduction associated with various states of verifiable vulnerability reduction or risk mitigation techniques.

Loss estimation is an essential tool to support insurance schemes, ensuring their financial viability, providing estimates of the premium rates which can be charged for various categories of risk (and reductions for mitigation) as well as providing the kind of information on likely losses which can stimulate individual and collective action. Loss estimation methods have been developing rapidly in recent years, but much of the progress has been done by commercial modelling companies, whose models are often seen as “black boxes”, producing loss data without explaining the methods (Bommer et al. 2006). New, open-source software models are being planned which could benefit administrations and insurers needing results, but unable to afford the commercial models.

4.12 Research needs

All of the above suggests some research needs, of a relatively unconventional kind, to support the practitioners of earthquake risk reduction.

First, there is a need to learn a lot more about the existing construction processes used by ordinary urban and rural households in the high-risk areas of the world. Any intervention which is going to be successful must start from and improve existing practices. A start could be made by monitoring in detail the reconstruction processes in Indonesia and Pakistan following recent earthquake disasters. An important component of this research would be to examine the impact and usefulness of the published reconstruction manuals and guidelines, and compare this impact with other sources of information or existing local expertise in influencing the reconstruction programme. How far do people have any real choice in siting, in building form and in construction technology? And what influence do aid agencies have?

Second, there is still a need for a big increase in our ability to gather data on the performance of buildings and other structures in earthquakes. At first sight it may seem that we already have a massive data collection capability; and certainly, for every big event today, many papers are published. But much of the data collection is rather superficial, and often assembled by overseas experts on short reconnaissance visits, with an overemphasis on what has been damaged rather than what has survived successfully. Systematic building-by-building studies of towns, km-by-km studies of highways, and person-by-person studies of affected households are rare, because they take time and trained people. A start could be made by better coordination of international and national reconnaissance teams, so that they collect data across the affected zone in a systematic way rather than all visit the same few damaged locations.

Third, we need to learn more about how to spread public awareness of earthquake risk. Programmes which have been successful need to be identified and the reasons for success explored. Earthquake protection has much to learn from public health programmes in this respect.

Another task is to extend laboratory investigations on means to improve the earthquake-resistance of ordinary building systems for housing, but to make sure that these are linked closely with "building for safety programmes" which will provide rapid feedback on the economic and practical constraints on alternatives proposed.

And we also need to learn more about the interrelationship between building damage and casualties in earthquakes, and how, even in the event of a intense ground shaking, small buildings could be prevented from reaching the damage state that causes serious and potentially fatal injuries. This is another topic which needs collaboration between engineers and health professionals; systematic data collection is needed to enable data from one earthquake to be compared with the next.

Earth observation from satellites is a sophisticated tool, with potential for viewing and recording what occurs at the Earth's surface without the need for extensive field data collection. How far can this tool help to save lives in the future? One way is to make available a detailed building-by-building picture of the damage within a few hours after an earthquake, to enable rescue teams to be directed to the worst affected areas (Saito et al. 2004). A second is, before an earthquake, to help build a detailed picture or inventory of what is at risk, so that the impact of probable earthquake scenarios can be modelled, in order to raise public awareness (Sarabandi et al. 2006). At the moment that potential has not been achieved, and there are operational difficulties; but in the future, with more powerful sensors and with more frequent satellite passes over even remote areas, and accompanying international protocols, such applications may become routine (Williamson 2006).

International collaboration at many levels will need to increase in order to realise these objectives: people exchanges, collaborative research projects; development aid and international finance, and the building of international organisations. Many channels already exist, and the challenge is to make better use of these rather than trying to create new structures.

5 Conclusion

Earthquake risk is growing, not shrinking, and that growth is concentrated in the uncontrolled new settlements of the cities of the Third World. It is made up of millions of small- and medium-sized houses, apartment blocks and commercial buildings which have been built without an awareness of the earthquake threat or of how to counter it. There is a common attitude, in the press and amongst political leaders even, that because large earthquakes are inevitable, future large death tolls are the inevitable consequence. But, as engineers and scientists with some knowledge of earthquakes and their effects, we need to challenge that attitude. We understand the threat, and we also have the technical understanding to build in such a way that buildings will not collapse. The current pace of reconstruction in the Third World cities is an opportunity to get things right.

This cannot happen overnight and it will not be easy. There needs to be a shift of emphasis in development aid towards mitigation as opposed to relief; and as Wisner has pointed out (Wisner 2004), efforts at disaster mitigation are frequently frustrated or negated by conflict or political instability. The effort must start with massive public awareness campaigns, with a huge extension of the education of building professionals, and with efforts to achieve better building control. We must convince politicians of the need for action, and ally ourselves with groups of individuals who are prepared to campaign for change. This will involve engineers and scientists in some unconventional activities and some unusual alliances. Research is needed to find cheaper ways to achieve resistance, and international collaboration will be necessary to transfer expertise and resources to the communities in the cities which most need it. But if death from infectious diseases can be dramatically reduced by concerted public health campaigns, so too can earthquake casualties; both are entirely avoidable with the technical means at our disposal.

This lecture has tried to suggest a few of the ways in which we might be able to act to reduce earthquake risks in the future, wherever in the world we live, work or travel. The task is achievable. But it is a challenge of global proportions.

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