1

Earthquake Risk Reduction

1.1 Introduction

Earthquake risk reduction is a complex affair involving many people of many vocations, much information, many opinions and many decisions and actions. The relationships between the contributing sets of information and people are illustrated schematically by the flowchart given in Figure 1.1. Considering that this diagram is necessarily simplified, it is clear that managing the changes needed to reduce earthquake risk is a challenging task in which all of the people in any given region are explicitly or implicitly involved. The largest component of earthquake risk reduction has traditionally been known as *earthquake resistant design*, the subject of Chapters 8–13.

1.2 Earthquake Risk and Hazard

In normal English usage the work *risk* means *exposure to the chance of injury or loss*. It is noted that the word *hazard* is almost synonymous with *risk*, and the two words are used in the risk literature with subtle variations which can be confusing.

Fortunately, an authoritative attempt has been made to overcome this difficulty through the publication by the Earthquake Engineering Research Institute's glossary of standard terms for use in this subject (EERI Committee on Seismic Risk, 1984). Their terminology will be used in this book.

Thus, the definition of *seismic risk* is *the probability that social or economic consequences of earthquakes will equal or exceed specified values at a site, at several sites, or in an area, during a specified exposure time*. Risk statements are thus given in quantitative terms.

Seismic hazard, on the other hand, is *any physical phenomenon (e.g. ground shaking, ground failure) associated with an earthquake that may produce adverse effects on human activities*. Thus, hazards may be either purely descriptive terms or quantitatively evaluated, depending on the needs of the situation. In practice, seismic hazard is often evaluated for given probabilities of occurrence, for example as for ground motions in Figure 4.48.

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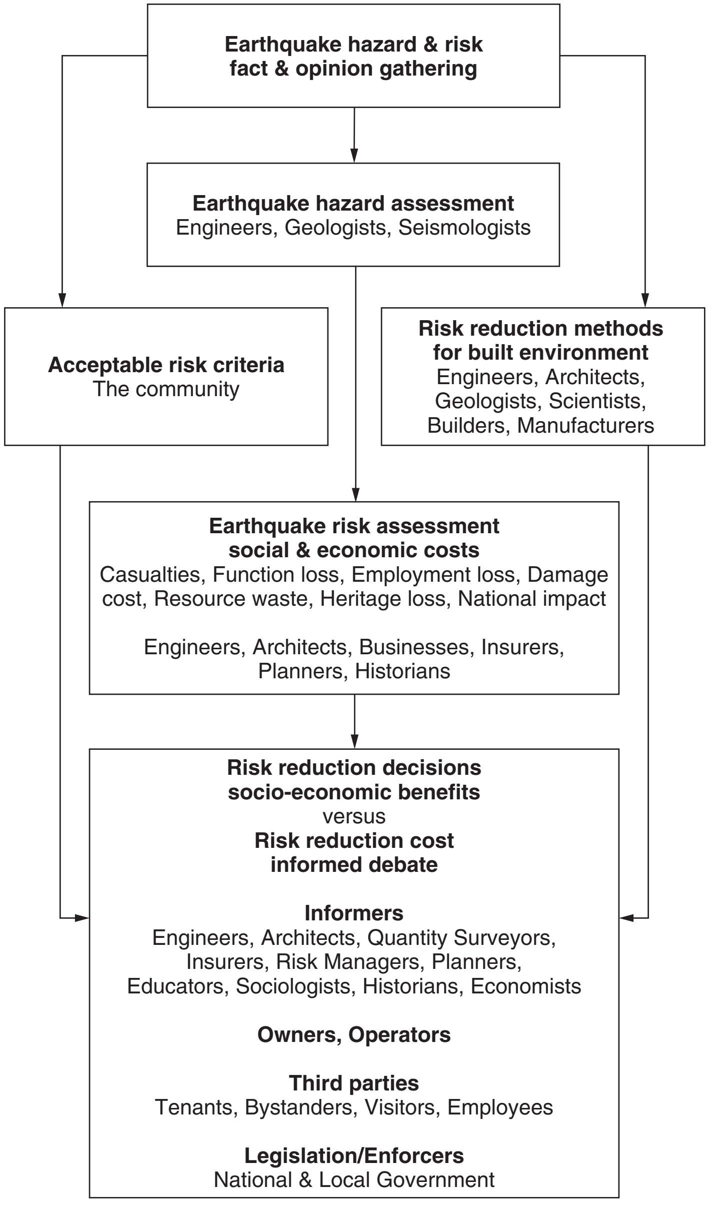

Figure 1.1 Information flow and those involved in the earthquake risk reduction process

It follows that seismic risk is an outcome of seismic hazard as described by relationships of the form

$$\text{Seismic risk} = (\text{Seismic hazard}) \times (\text{Vulnerability}) \times (\text{Value}) \tag{1.1}$$

where *Vulnerability* is the amount of damage, induced by a given degree of hazard, and expressed as a fraction of the *Value* of the damaged item under consideration. Referring to Figure 6.7(a), the monetary seismic risk to a building could be evaluated by taking the seismic hazard to be the Modified Mercalli intensity of the appropriate probability of occurrence, the vulnerability would then be taken as the damage ratio on the appropriate curve for that intensity, and the value would be the replacement cost.

For design or risk assessment purposes the assessment of seismic hazard consists of the following basic steps:

(1) definition of the nature and locations of earthquake sources;
(2) magnitude–frequency relationships for the sources;
(3) attenuation of ground motion with distance from source;
(4) determination of ground motions at the site having the required probability of exceedance.

Because seismic risk and hazard statements are essentially forecasts of future situations, they are inherently *uncertain*. Seismic hazard assessments are attempts to forecast the likely future seismic activity rates and strengths, based on knowledge of the past and present, and significant uncertainties arise partly because the processes involved are not fully understood and partly because relevant data are generally scarce and variable in quality. For reasonable credibility considerable knowledge of both *historical seismicity* and *geology* need to be used, together with an appropriate analysis of the uncertainties. Seismicity is defined as the frequency of occurrence of earthquakes per unit area in a given region, and is illustrated in non-numerical terms by the seismicity map of the world presented in Chapter 2 (Figure 2.1). Where available, other geophysical or seismological knowledge, such as crustal strain studies, may also be helpful, particularly in evaluating regional seismic activity patterns. Once both the estimated future seismic-activity rates and the acceptable risks are known, appropriate earthquake loadings for the proposed structure may be determined, for example, loadings with mean recurrence intervals of 100 to more than 10,000 years, depending on the consequences of failure.

Because of the difficulties involved in seismic hazard evaluation, earthquake design criteria in different areas of the world vary, from well codified to inadequate or non-existent. Hence, depending on the location and nature of the project concerned, seismic risk evaluation ranging from none through arbitrary to thoroughgoing may be required.

The whole of this book is essentially to do with the explicit or implicit management of seismic risk, and hence the foregoing brief introduction to risk and hazard will be expanded upon in the subsequent text.

1.3 The Social and Economic Consequences of Earthquakes

1.3.1 Earthquake consequences and their acceptability

The primary consequence of concern in earthquakes is of course human casualties, i.e. deaths and injuries. According to Steinbrugge (1982), the greatest known number of deaths that have occurred in a single event is 830,000, in the Shaanxi, China, earthquake

Table 1.1 Numbers of deaths caused by a selection of larger twentieth-century earthquakes in various countries (from Steinbrugge, 1982, and NEIC web page)

Date	Location	Magnitude	Deaths
1906 Apr 18	USA, San Francisco	7.8	800
1908 Dec 28	Italy, Messina	7.5	83,000
1923 Sep 1	Japan, Tokyo	7.9	142,807
1927 May 22	China, Nan-Shan	8.3	200,000
1935 May 31	India, Quetta	7.5	30,000–60,000
1939 Jan 24	Chile, Chillan	8.3	28,000
1939 Dec 26	Turkey, Erzincan	7.9	30,000
1949 Aug 5	Ecuador, Pelileo	6.8	6,000
1956 Jun 10–17	Northern Afghanistan	7.7	2,000
1957 Dec 4	Outer Mongolia, Gobi-Altai	8.6	1,200
1960 Feb 29	Morocco, Agadir	5.6	12,000
1962 Sep 1	Northwestern Iran	7.1	12,230
1963 Jul 26	Yugoslavia, Skopje	6.0	1,100
1970 May 31	Northern Peru	7.8	66,794
1972 Dec 23	Nicaragua	6.2	5,000
1974 Dec 28	Pakistan	6.2	5,300
1976 Feb 4	Guatemala	7.5	23,000
1976 Jul 28	China, Tangshan	7.9	245,000–655,000
1976 Aug 17	Philippines, Mindanao	7.9	8,000
1977 Mar 4	Romania, Bucharest	7.2	1,500
1978 Sep 16	Northeast Iran	7.7	25,000
1980 Oct 10	Algeria	7.2	3,000
1985 Sep 19	Mexico	8.1	9,500–30,000
1995 Jan 10	Japan, Kobe	6.9	5,500
1999 Aug 17	Turkey, Koeceli	7.4	17,439
1999 Sep 20	Taiwan, Chi-Chi	7.6	2,400

of January 24, 1556. Thus the number of casualties in any given event varies enormously, depending on the magnitude, location and era of the earthquake. This is illustrated by a selection of 26 of the more important earthquakes of the twentieth century (mostly drawn from Steinbrugge, 1982) as listed here in Table 1.1. These earthquakes occurred in 24 countries in most parts of the world, and range in magnitude from 6.0 to 8.6. Many of the higher casualty counts have been caused by the collapse of buildings made of heavy, weak materials such as unreinforced masonry or earth. Safety in houses in developing countries remains our biggest challenge (Comartin *et al*., 2004).

In Figure 1.2 are plotted the approximate total numbers of deaths in earthquakes that occurred worldwide in each decade of the twentieth century. This histogram highlights the randomness of the size and location of the earthquake occurrence process, as well as the appalling societal cost, and implied economic cost, of earthquakes. The totals were found by summing the deaths in major earthquakes listed by Steinbrugge (1982) and the NEIC. The totals for each decade do not include deaths from events with less than 1000 casualties, one of the larger omissions being the 1931 Hawke's Bay, New Zealand, earthquake in which about 260 people died (Dowrick and Rhoades, 2005).

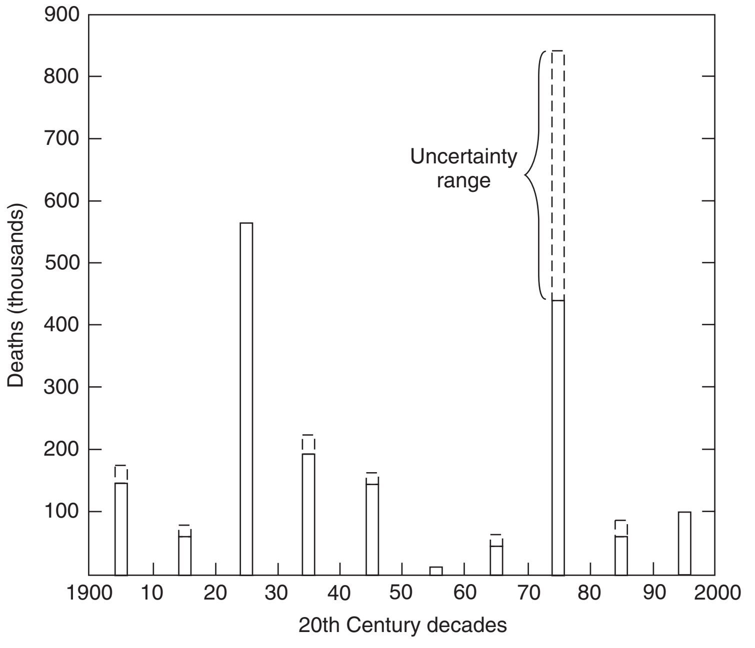

Figure 1.2 Numbers of deaths worldwide caused by large earthquakes in each decade of the twentieth century

The physical consequence of earthquakes for human beings are generally viewed under two headings:

(A) death and injury to human beings;
(B) damage to the built and natural environments.

These physical effects in turn are considered as to their social and economic consequences:

(1) numbers of casualties;
(2) trauma and bereavement;
(3) loss of employment;
(4) loss of employees/skills;
(5) loss of heritage;
(6) material damage cost;
(7) business interruption;
(8) consumption of materials and energy (sustaining resources);
(9) macro-economic impacts (negative and positive).

The above physical and socio-economic consequences should all be taken into account when the acceptable consequences are being decided (i.e. the acceptable earthquake risk).

Both financially and technically, it is possible only to *reduce* these consequences for strong earthquake shaking. The basic *planning aims* are to minimize the use of land subject to the worst shaking or ground damage effects, such as fault rupture, landslides or liquefaction. The basic *design aims* are therefore confined (a) to the reduction of loss of life in any earthquake, either through collapse or through secondary damage such as falling debris or earthquake induced fire, and (b) to the reduction of damage and loss of use of the built environment. (See also Section 6.3.7.)

Obviously, some facilities demand greater earthquake resistance than others, because of their greater social and/or financial significance. It is important to determine in the design brief not only the more obvious intrinsic value of the structure, its contents, and function or any special parts thereof, but also the survival value placed upon it by the owner.

In some countries the greater importance to the community of some types of facility is recognized by regulatory requirements, such as in New Zealand, where various public buildings are designed for higher earthquake forces than other buildings. Some of the most vital facilities to remain functional after destructive earthquakes are dams, hospitals, fire and police stations, government offices, bridges, radio and telephone services, schools, energy sources, or, in short, anything vitally concerned with preventing major loss of life in the first instance and with the operation of emergency services afterwards. In some cases, the owner may be aware of the consequences of damage to his property but may do nothing about it. It is worth noting that, even in earthquake conscious California, it is only since the destruction of three hospitals and some important bridges in the San Fernando earthquake of 1971 that there have been statutory requirements for extra protection of various vital structures.

The consequences of damage to structures housing intrinsically dangerous goods or processes is another category of consideration, and concerns the potential hazards of fire, explosion, toxicity, or pollution represented by installations such as liquid petroleum gas storage facilities or nuclear power or nuclear weapons plants. These types of consequences often become difficult to consider objectively, as strong emotions are provoked by the thought of them. Acknowledging the general public concern about the integrity of nuclear power plants, the authorities in the United Kingdom decided in the 1970s that future plants should be designed against earthquakes, although that country is one of low seismicity and seismic design is not generally required.

Since the 1960s, with the growing awareness of the high seismic risks associated with certain classes of older buildings, programmes for strengthening or replacement of such property have been introduced in various parts of the world, notably for pre-earthquake code buildings of lightly reinforced or unreinforced masonry construction. While the substantial economic consequences of the loss of many such buildings in earthquakes are, of course, apparent, the main motivating force behind these risk-reduction programmes has been social, i.e. the general attempt to reduce loss of life and injuries to people, plus the desire to save buildings or monuments of historical and cultural importance.

While individual owners, designers, and third parties are naturally concerned specifically about the consequences of damage to their own proposed or existing property, the overall effects of a given earthquake are also receiving increasing attention. Government departments, emergency services, and insurance firms all have critical interests in the physical and financial overall effects of large earthquakes on specific areas. In the case of insurance companies, they need to have a good estimate of their likely losses in any single large catastrophe event so that they can arrange sufficient reinsurance if they are over-exposed to seismic risk. Disruption of lifelines such as transport, water, and power systems obviously greatly hampers rescue and rehabilitation programmes.

1.3.2 Economic consequences of earthquakes

Figure 1.3 plots the costs of earthquake material damage worldwide per decade in the twentieth century, where known. The data for the second half of the century comes from Smolka (2000) of Munich Reinsurance. The first half of the century is incomplete, only the material damage costs for the 1906 San Francisco and the 1923 Kanto earthquakes being readily found. As with the twentieth century deaths sequence plotted in Figure 1.2, the costs sequence is seen to be random. However, there is no correlation between the deaths and costs sequences. It appears that if the costs were normalized to a constant population, and if the 1995 Kobe earthquake were not included, there would be no trend to increase

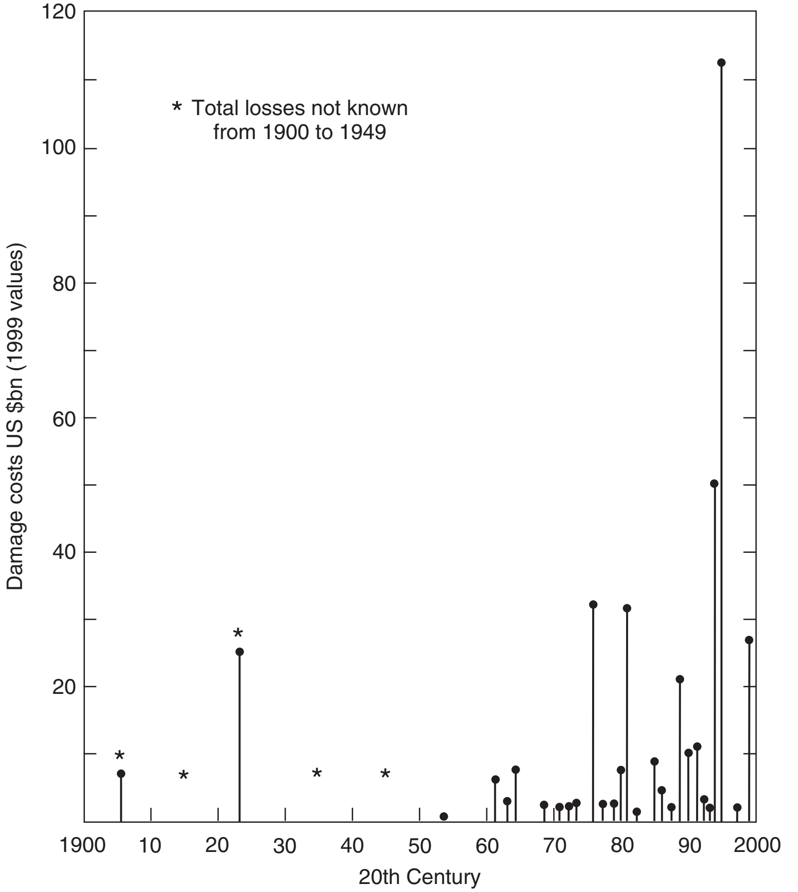

Figure 1.3 Total costs of earthquake material damage worldwide for each decade of the twentieth century (adapted from Smolka, 2000). Reproduced by permission of the Munich Reinsurance Company

with time. However, the global seriousness of earthquake damage losses is undisputed. The economic consequences of earthquakes occur both before and after the event. Those arising before the event include protection provisions such as earthquake resistance of new and existing facilities, insurance premiums, and provision of earthquake emergency services. Insurance companies themselves need to reinsure against large earthquake losses, as mentioned in the previous section.

Post-earthquake economic consequences include:

(1) cost of death and injury;
(2) cost of damage;
(3) losses of production and markets;
(4) insurance claims.

The direct cost of damage depends upon the nature of the building or other type of facility, its individual vulnerability, and the strength of shaking or other seismic hazard to which it is subjected.

During the briefing and budgeting stages of a design, the cost of providing earthquake resistance will have to be considered, at least implicitly, and sometimes explicitly, such as for the retrofitting of older structures. The cost will depend upon such things as the type of project, site conditions, the form of the structure, the seismic activity of the region, and statutory design requirements. The capital outlay actually made may in the end be determined by the wealth of the client and his or her attitude to the consequences of earthquakes, and insurance to cover losses.

Unfortunately it is not possible to give simple guides on costs, although it would not be misleading to say that most engineering projects designed to the fairly rigorous Californian or New Zealand regulations would spend a maximum of 10% of the total cost on earthquake provisions, with 5% as an average figure.

The cost of seismic upgrading of older buildings varies from as little as 10% to more than 100% of the replacement cost, depending on the nature of the building, the level of earthquake loadings used, and the amount of non-structural upgrading that is done at the same time as the strengthening. It is sad to record that many fine old buildings have been replaced rather than strengthened, despite it often being much cheaper to strengthen than to replace.

Where the client simply wants the minimum total cost satisfying local regulations, the usual cost-effectiveness studies comparing different forms and materials will apply. For this a knowledge of good earthquake resistant forms will, of course, hasten the determination of an economical design, whatever the material chosen.

In some cases, however, a broader economic study of the cost involved in prevention and cure of earthquake damage may be fruitful. These costs can be estimated on a probabilistic basis and a cost-effectiveness analysis can be made to find the relationship between capital expenditure on earthquake resistance on the one hand, and the cost of repairs and loss of income together with insurance premiums on the other.

For example, Elms and Silvester (1978) found that in communal terms the capital cost savings of neglecting seismic design and detailing would be more than offset by the increased economic losses in earthquakes over a period of time in any part of New Zealand. It is not clear just how low the seismic activity rate needs to be for it to be cheaper in the long term for any given community to omit specific seismic resistance provisions. The availability or not of private sector earthquake insurance in such circumstances would be part of the economic equation.

Hollings (1971) discussed the earthquake economics of several engineering projects. In the case of a 16-storey block of flats with a reinforced concrete ductile frame it was estimated that the cost of incorporating earthquake resistance against collapse and subsequent loss of life was 1.4% of the capital cost of building, while the cost of preventing other earthquake damage was reckoned as a further 5.0%, a total of 6.4%. The costs of insurance for the same building were estimated as 4.5% against deaths and 0.7% against damage, a total of 5.2%. Clearly, a cost-conscious client would be interested in putting up a little more capital against danger from collapse, thus reducing the life insurance premiums, and he or she might well consider offsetting the danger of damage mainly with insurance.

Loss of income due to the building being out of service was not considered in the preceding example. In a hypothetical study of a railway bridge, Hollings showed that up to 18% of the capital cost of the bridge could be spent in preventing the bridge going out of service, before this equalled the cost of complete insurance cover.

In a study by Whitman *et al*. (1974), an estimate was made of the costs of providing various levels of earthquake resistance for typical concrete apartment buildings of different heights, as illustrated on Figure 1.4. Until further studies of this type have been done, results such as those shown in the figure should be used qualitatively rather than quantitatively.

It is most important that at an early stage the owner should be advised of the relationship between strength and risk so that he can agree to what he is buying. Where stringent earthquake regulations must be followed the question of insurance versus earthquake resistance may not be a design consideration: but it can still be important, for example for designing non-structural partitions to be expendable or if a ‘fail-safe’ mechanism is proposed for the structure. Where there are loose earthquake regulations or none at all, insurance can be a much more important factor, and the client may wish to spend little on earthquake resistance and more on insurance.

However, in some cases insurance may be more expensive, or unavailable, for facilities of high seismic vulnerability. For example, the latter is often the case for older unreinforced masonry buildings in some high seismic risk areas of New Zealand, i.e. those built prior to the introduction of that country’s earthquake loadings code in 1935. The costs of earthquake damage are discussed further in Chapter 7.

1.4 Earthquake Risk Reduction Actions

To reduce earthquake risk, each country needs to examine its strengths and weaknesses, build on the strengths, and systematically take actions which reduce or eliminate the weaknesses. An example of such an approach comes from New Zealand where a list of weaknesses was identified (Dowrick, 2003).

Over a score of weaknesses were identified there in a preliminary list of weaknesses of a wide range of types. The weaknesses have been initially divided into two main categories, named *strategic* and *tactical*, as listed in Tables 1.2(a) and 1.2(b), respectively. This division in some cases is somewhat arbitrary, but it helps in comprehending

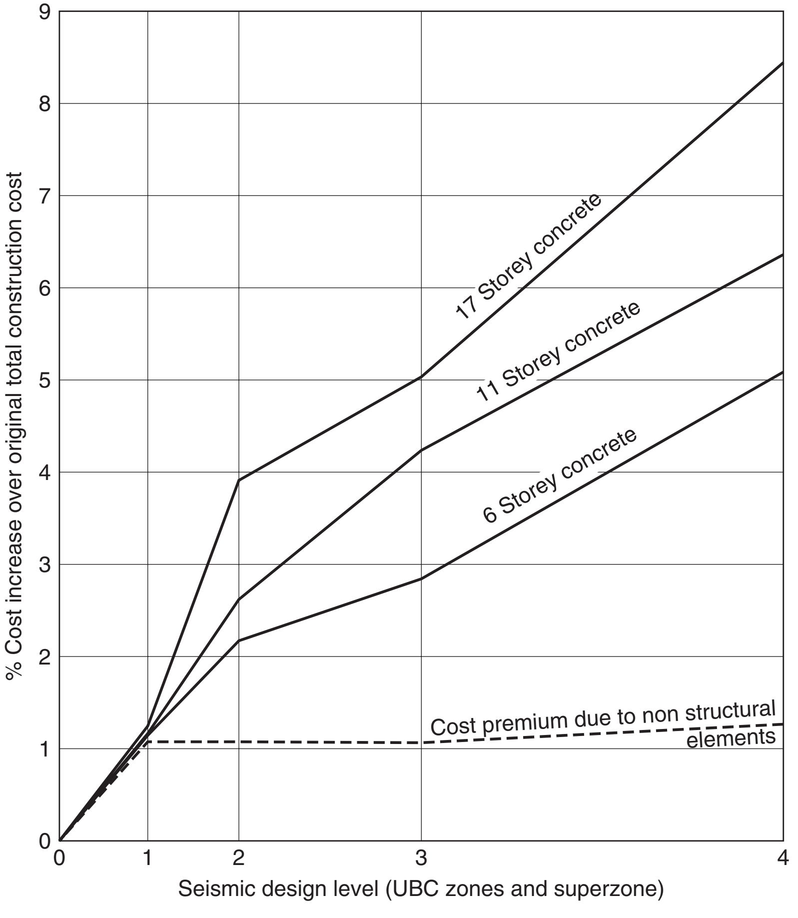

Figure 1.4 Effect on cost of earthquake resistant design of typical concrete apartment buildings in Boston (after Whitman *et al*., 1974)

the considerable detail implied by the abbreviated descriptions given to the tabulated weaknesses.

Consider the 11 *strategic* weaknesses listed in Table 1.2(a). The first of these is clearly strategic, noting that New Zealand has no national strategy for managed progressive reduction of earthquake risk. What was needed were monitored goals of target risk reductions in a series of (say) five-year plans, with priorities assigned at both a national and a local level.

As well as listing weaknesses, Tables 1.2(a) and 1.2(b) attempt to list all parties who contribute to remedying each of the weaknesses. The first of these is *advocacy* by earthquake professionals (engineers, geologists, seismologists, architects, economists, planners, risk managers and others), and another is *funding* (rather than people). The remaining nine entities, ranging from engineers to central government, illustrate the complexity of the workings of modern society, which by fragmentation constitutes a considerable difficulty

Table 1.2 (a) Part 1 of the list of New Zealand's weaknesses in earthquake risk reduction (from Dowrick, 2003)

A	Undesirable situations – strategic	Remedial action by whom										
		A	E	a	I	M	P	G	g	L	F	O
A1	No national strategy and targets for managed incremental risk reduction with time	A	E	–	–	M	–	G	g	L	–	–
A2	Too much national vulnerability to a 'king-hit' earthquake on Wellington	A	–	–	–	M	–	G	–	L	–	–
A3	Fragmentation of the many endeavours contributing to earthquake risk reduction	A	–	–	–	–	P	G	g	L	–	–
A4	Underfunding of production of design codes and standards	A	–	–	–	–	–	G	–	–	F	–
A5	Systematic reduction of the numbers of hospitals/beds nationwide	A	–	–	–	–	P	G	g	–	F	–
A6	Too little management/modelling of business interruption losses	A	–	–	I	M	P	G	g	L	–	O
A7	Slow uptake of some new research findings	A	–	–	–	–	P	G	g	L	F	O
A8	As yet no official process for retrofitting of non-URM earthquake risk buildings	A	E	–	–	–	–	G	g	L	–	O
A9	Too much emphasis on life safety at the expense of high damage (e.g. EBFs)	A	E	–	–	–	–	–	–	–	–	O
A10	Over-design in New Zealand's lowest seismic hazard regions	–	E	–	–	–	P	–	–	L	–	–
A11	Architects who don't collaborate with engineers structural form needs	A	–	a	–	–	–	–	–	–	–	O

Notes: A = Advocacy by earthquake professions; a = Architects; E = Engineers; F = Funding needed; G = Central government; g = Government department; I = Insurance industry; L = Local government; M = Economists; O = Owners of property; P = Planners. EBF = Eccentrically braced frame; URM = Unreinforced masonry.

(i.e. a weakness) as listed in item A3. As given in Table 1.2(a), central government (G), government departments (g), local government (L) and planners (P) are all needed to address this problem, in addition to the advocacy role of earthquake professionals.

Item A10, over-design in New Zealand's lowest seismic hazard regions, results from the historical excessive conservatism of design loadings for northern regions of the North Island, a situation which was expected to be resolved in the then proposed revision of the loadings standard. This is listed as a weakness in order to illustrate the need to spend

Table 1.2 (b) Part 2 of the list of New Zealand's weaknesses in earthquake risk reduction (from Dowrick, 2003)

B	Undesirable situations – tactical	Remedial action by whom										
		A	E	a	I	M	P	G	g	L	F	O
B1	No earthquake regulations for most equipment and plant	A	E	–	–	–	–	G	g	–	–	–
B2	Inadequate earthquake regulations for building services in buildings	A	E	–	–	–	–	G	–	L	–	O
B3	Inadequate earthquake regulations for storage of stock in shops and warehouses	A	E	–	–	–	–	G	g	L	–	O
B4	No adequate regulatory framework for existing high-risk concrete and steel buildings	A	E	–	–	–	–	G	g	–	–	–
B5	Weak powers and weak action for pre-emptive land-use planning (f,l,*l*,m)[1]	A	–	–	–	–	P	G	–	L	–	–
B6	Buildings astride active faults	A	*EG*[2]	–	I	–	P	–	g	L	–	O
B7	Modern buildings built without measures for liquefiable ground	A	E	–	–	–	P	–	–	L	–	O
B8	Inadequate enforcement of some regulations	A	E	–	I	–	P	G	–	L	–	O
B9	Incomplete and/or inadequate microzoning maps nationwide	A	*EG*	–	–	–	P	–	–	L	–	–
B10	Some councils renting out or using earthquake risk buildings	A	E	–	I	–	P	–	–	L	–	–
B11	Are all new materials and techniques adequately researched before use? (e.g. 'chilly bins')	A	E	–	I	–	–	–	g	L	–	–
B12	No regular checks on seismic movement gaps for seismically isolated structures	A	E	–	I	–	–	–	–	L	–	O

Notes:
[1](f, l, *l*, m) = faults, landslides, liquefaction, microzoning.
[2]*EG* = Engineers + geologists. For explanation of other abbreviations A, E, etc. see Table 1.2(a).

New Zealand's limited national financial resources wisely, and emphasize the need for national priorities for risk reduction as discussed above for item A1.

Let us now turn to the 12 *tactical* weaknesses, listed in Table 1.2(b), which generally involves more technical detail than the *strategic* weaknesses of Table 1.2(a). This is illustrated by the fact that in the *actions by whom* lists, engineers (E) appear in 11 items of Table 1.2(b) and only four of Table 1.2(a). As indicated by items B1–B4, many components of the built environment are inadequately regulated for earthquake risk purposes. The lack of mandatory regulations for earthquake protection of most built or manufactured items other than buildings is a historical situation (common worldwide) which strongly merits rectification in the interests of earthquake risk reduction. The case of stored goods (stock) in shops (item B3) is a curious and alarming example. Consider the way that goods are stacked in some shops. Lethally heavy goods are stacked needlessly high overhead in the most dangerous fashion to anyone below. The fact that loose goods or contents of buildings fall to the floor in moderate or strong shaking is common knowledge.

These situations are, in fact, a breach of the New Zealand law regarding the safety of the shop employees, and it was surprising and disappointing that the government agency, Occupational Safety and Health (OSH), had not stamped out this practice. The deaths and injuries of workers and public alike would be on the slate of the owners, OSH staff and the government, if this situation is not eliminated before the next damaging earthquake. Oddly, the New Zealand public had no statutory protection from this source of danger at the time of this study, and still had none in 2007.

In the more seismic parts of New Zealand two types of older buildings, of unreinforced masonry (URM) and some concrete buildings (item B4), pose a serious threat. While many brick buildings have been demolished or strengthened in some parts of the country, the process has been somewhat erratic, such that in 2008 there were some 5000 unstrengthened URM buildings countrywide. Even in Wellington where the City Council has been a leader in this field since about 1980, many old unreinforced brick buildings were still in use in 2008, death traps to occupants and passers-by. (However, recent changes to the Building Act should see a steady improvement in the rate of dealing with such buildings.) We might also ask why long-vacated brick buildings should not be demolished forthwith. They pose a great threat to passers-by.

The older concrete buildings that are at risk of serious earthquake damage (item B4), comprise mainly pre-1976 multi-storey buildings, which have beam and column frames rather than structural walls. In the past decade or two much work has been done in various countries such as the USA and New Zealand. In the latter country the outcome has been the publication of recommendations which cover initial evaluation, detailed assessment and improvement of structural performance (if required) of all existing buildings (New Zealand Society for Earthquake Engineering, 2006). Similar recommendations for the USA are given in FEMA-356 (American Society of Civil Engineers, 2000). The issue of what to do about substandard buildings is rightly contentious as the costs of strengthening will be considerable in many cases. Details of strengthening are discussed in Chapter 13.

An important aspect of Tables 1.2(a) and 1.2(b) is the influence of *duty of care* on who could be involved in remedial actions. Duty of care is the common law responsibility of a person or body to do something, such as warning others about a situation that they know to be dangerous, even if they are not involved, or if there is no statutory requirement. For example, building on an active fault (item B6) is known by most people to be dangerous, so that in addition to geologists, those who could act on this danger to people and property include engineers, architects, insurers, planners, government departments, local government and the owner of the building.

As the duty of care is surprisingly pervasive, Tables 1.2(a) and 1.2(b) should be widely distributed to all concerned.

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