WHAT CAN WE DO ABOUT EARTHQUAKES? TOWARDS A SYSTEMATIC APPROACH TO SEISMIC RISK MITIGATION

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ABSTRACT

This paper discusses the possible means of achieving risk reduction and resilience against earthquake disasters. It begins with an enquiry into the evolving nature of the resilience concept, which has at its root the notions of participatory governance and livelihood protection. It then discusses the potential for saving human lives by greater utilisation of the evidence base derived from studies of earthquake epidemiology. For example, there may be an opportunity to improve self-protective behaviour as a means of reducing casualties, especially in combination with knowledge of typical modes of the performance of buildings during earthquakes. There follows a discussion of the particular seismic vulnerability of critical infrastructure, hospitals and schools, and the means of reducing it by planning and well-calculated intervention. Seismic risk management needs to be comprehensive and often neglects some important factors. Hence, the next section discusses three of them: the plight of minorities, the protection of cultural heritage, and the management of veterinary emergencies. Following this, there is a discussion of the requirements for viable recovery from earthquake disasters. These include the need to make reconstruction, risk reduction and emergency intervention sustainable in their own right and part of general sustainability against all of the major risks that society faces. The paper concludes with some brief reflections on the process of learning lessons, as seen in the light of organisational learning theory. The use of evidence-based practice to achieve seismic disaster risk reduction has much further to go. To be accepted, it needs to be assimilated permanently into prevailing social and organisational cultures.

Key words: Earthquake disaster, Disaster risk reduction, Resilience, Critical infrastructure protection, Seismic safety of school and hospitals, Recovery from disaster, Organisational learning.

1 FROM DISASTER RISK REDUCTION TO RESILIENCE

It has been known since the 1970s that the benefit-cost ratios of natural disaster risk mitigation are positive, and sometimes spectacularly so (Leighton 1976). To spend money on reducing risks is usually considerably cheaper than to lay out money on dealing with the consequences of disaster. Thus, society has long recognised the need to divert funds from reacting to disaster to works of prevention (Alesch and Petak 1986). Paradoxically, relatively little has been done to accomplish this, and there are several reasons why. The first is that disaster response is unavoidable and total disaster prevention is in most cases impossible. Secondly, there are few political advantages in mitigation. Disasters obviously have a negative image and although their reduction is evidently a good idea, it is seldom a vote-winner. This reflects the low frequency of major disasters and the tendency of both politicians and the public to ignore or minimise the risk during times of quiescence—a form of gambling with fate. Thirdly, disaster victims are voters, and 'forgiveness money' (subvention to people who did not reduce their risks) is politically expedient and carries few stigma. For example, in the United States the number of Presidential declarations of states of disaster or emergency has risen from 20 per annum in the late 1970s to between 75 and 100 at present—in other words far faster than the rise in the number of disasters (Salkowe and Chakraborty 2009).

Despite decades of inaction, attitudes began to change in the 2000s. Following the International Decade for Natural Disaster Reduction (1990-2000), the emphasis slowly began to shift from reaction to pre-emptive action, and thus the concepts of disaster risk reduction (DRR) and resilience (UNISDR 2005) emerged. In reality, the idea of resilience (or resiliency) was coined a century before around 1909, when it was used in mechanics to denote a material that possessed an optimum combination of strength to resist brittle fracture and ductility to absorb an applied stress (Alexander 2012). Resilience was applied to textile manufacture in the 1930s

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(Hoffman 1948), ecology in the 1960s (Holling 1967) and psychology in the 1990s (Rutter 1987). In disaster risk reduction, resilience refers, by analogy with materials testing, to the ability of the social system to resist a shock and absorb its effects (Berkes 2007).[1] For instance, higher levees can resist moderate but perhaps not exceptional flooding but when they are overtopped evacuation can protect people against drowning, or, better still, land-use control can allow the flooding of properties to be avoided. In terms of recovery from disasters, resilience was originally conceptualised as the ability to 'bounce back' and restore normal lives and livelihoods rapidly after an impact (Aven 2011). It has since come to mean the ability to move to a higher state of preparedness, as exemplified in the campaigns to "build back better" and thus not to recreate pre-existing vulnerabilities. The positive side of disaster is that, in revealing vulnerabilities, it provides the opportunity to reduce them (Birkmann 2006).

Either in times of quiescence or of disaster, vulnerability reduction requires that there be a consensus between politicians, the professional classes and stakeholders in the community (Alexander 2007). Although the term 'governance', widely employed in this context, strictly refers only to the process of government, whatever that implies, in reality it should describe a process of consensus building and participatory democracy that represents the best way to ensure community resilience in the face of disaster risk. Governance is thus at the root of the complex processes of disaster risk reduction (Qian 2010). Moreover, since the 1970s it has been recognised that vulnerability is a clearer diagnostic of disaster risk than is hazard (Hewitt 1983). Hence, the parameters that characterise an earthquake—magnitude, acceleration, hypocentral depth, bracketed duration, frequency pattern, etc.—are less able to predict the socio-economic effects of a seismic disaster than are factors related to the vulnerability of people, their dwellings and environments, and their economic activities (Wisner 1996).

In recovery from disaster another vital factor is the preservation or regeneration of livelihoods. It is recognised that full recovery is difficult without this, as the disaster area would otherwise remain dependent on external aid, which is often unreliable and very seldom continuous over long periods of time (Cannon 2006). One negative example is that of the earthquake which occurred at L'Aquila in central Italy on 6 April 2009. Job losses from the province of L'Aquila totalled 16,000 over the year (the population of the province is slightly less than 300,000). Coupled with a poor and unimproved infrastructure, the local economy stagnated and so did recovery and reconstruction processes (Alexander 2010).

Despite the central importance of these two factors—participatory governance and livelihood protection—resilience against earthquakes is made up of a variety of different factors, which this paper will now examine in order to determine the current state of play regarding knowledge of the risks and how best to reduce them. I will start by considering earthquake epidemiology, a field that has great unfulfilled potential to contribute to seismic risk mitigation. I will then consider the vulnerability of critical infrastructure, with particular attention to hospitals and schools. This will be followed by a brief consideration of some important but neglected aspects of seismic risk mitigation planning, and finally I will consider the possible routes to sustainable recovery after an earthquake has struck.

2 EARTHQUAKE EPIDEMIOLOGY: THE LOST OPPORTUNITY

In the 1980s a multidisciplinary group was started in the USA with the objective of contributing to a casualty estimation module of the new GIS-based tool for earthquake risk estimation, HAZUS - Hazards in the United States. Unfortunately, once the module was made, the group disbanded, following a decade of sharing information and advocating a more systematic approach to research on the processes by which earthquakes cause deaths and injuries (Stojanovski and Dong 1994). Since then, progress in this field has been remarkably slow (Spence *et al*. 2011). In part, this is because there are enormous variations in the patterns of casualties from one place to another, and in part it is because there are formidable obstacles to data collection and analysis; for example, in many cases, patients' medical records remain confidential and inaccessible, even in generalised form. Nonetheless, one is forced to conclude that progress has also been inhibited by lack of systematic interest on the part of researchers and policy makers.

Nevertheless, there is a strong and largely unfulfilled need for evidence-based practice in earthquake epidemiology (Jenkins et al. 2008). It has been established, largely because it is self-evident, that casualties in earthquakes are overwhelmingly the result of structural collapse (Coburn *et al.* 1992). However, relatively little is known about the interaction between patterns of collapse and the way that occupants use buildings. The evidence on human actions during earthquakes is patchy, and hence it is difficult to know the extent to which self-protective behaviour saves lives, or conversely the extent to which rash behaviour increases people's risk of death or injury. Above all, there has been little attempt to move from an anecdotal level, in which the evidence is fragmentary and sometimes contradictory, to a level at which a systematic review is possible. Earthquake injury data are not internationally notifiable, and there have long been problems with basic definitions, especially of what constitutes a significant injury. Even death statistics have been complicated by delayed and background mortality. Finally, in New Zealand, following the thousands of injuries recorded by the Accident Compensation Commission (ACC) and attributed to the Canterbury earthquakes, some evidence-based research into the behaviours associated with earthquake injuries is under way (Johnston *et al.,* in prep).

The findings of earthquake epidemiology can be accessed in

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[1] Some researchers in disaster risk reduction use the ecological formulation of the resilience concept devised by Holling (1967), but this rather restricted systems view is of limited explanatory power regarding socio-economic systems and it is better to return to the original, rather broader view of the term promoted in mechanics.

various publications (Seaman *et al.* 1984, Noji 1997, Spence *et al.* 2011). Only the the broad picture is summarised here. On average, 28-30 earthquake disasters occur each year, including those whose impact results from a seismic sea wave. During the 2000s the mean annual death toll was 68,000, although it varies by two orders of magnitude from year to year. Some 8.7 million people are affected by earthquakes per annum. Damage averages US$23 billion per year, which among natural disasters is second only to hurricanes, and 60 per cent of earthquake disasters occur in Asia (IFRCRCS 2011). Looking at time trends, one would like to be able to say that death tolls have remained stable or have fallen despite the incessant rise in costs associated with seismic disasters, but the occurrence of several major events belies this assumption: almost 300,000 people died in the Indian Ocean earthquake and tsunami of 26 December 2004 and perhaps 230,000 died in the Haiti earthquake of 12 January 2010. The potential for considerably higher loss of life exists in cities such as Tehran, Istanbul and Kathmandu.

The diffusion across the world's seismic zones of frame buildings (in reinforced concrete or steel) has helped reduce the number of casualties in earthquakes (Coburn and Spence 2002). This is true despite the fact that in certain events (notably the 1985 Mexico earthquake and 1999 Marmora (İzmit), Turkey disaster) there have been high death tolls in the collapse of inadequately constructed frame buildings (Ellidokuz *et al*. 2005).

In most earthquakes, casualties are strongly concentrated in the epicentral area, and they show an exponential decay with distance that is parallels seismic attenuation. Small, vulnerable settlements with epicentral locations may lose up to 85 per cent of their building stock and have death tolls that exceed 10 per cent of their populations (Coburn and Spence 2002). However, remarkably few earthquakes cause absolute destruction and the more common picture is a broad pattern of damage punctuated by a limited number of spectacular collapses. In most lethal earthquakes, the death toll is thus critically dependent on the occupancy levels of the collapsed buildings (Griffiths *et al*. 2007).

Despite a gradual reduction in the proportion of unreinforced masonry buildings, it remains true for the majority of the world's seismic zones that the greatest risk of casualties occurs in nocturnal earthquakes. The New Zealand Darfield earthquake of 4 September 2010, at 04:35 local time, was one of the exceptions. There is no discernible variation in seismicity with time of day, but up to 90 per cent of deaths and injuries may occur in earthquakes that occur at night while the majority of people are sleeping (as earthquake disasters produce highly irregular statistics, the exact proportion is highly dependent on the length of the time-series analysed). This highlights the vulnerability of vernacular housing and its occupants (Alexander 1996).

Earthquake epidemiology is the study of the patterns of death, injury, disability and disease resulting from seismic activity (Seaman *et al.* 1984). Given that earthquakes usually do not cause epidemics, the emphasis is on interpreting the patterns of direct casualty. However, despite decades of research many important aspects are still poorly understood, in part because the research has tended to be fragmentary, often anecdotal and rarely systematic. The other reason why our understanding is limited is that earthquake casualties are highly variable from one event to another, as they depend on a wide variety of controlling factors: time of day and patterns of aggregate activity; site-specific population density; quality, design, state of maintenance and dynamic performance of building stock; and so on. Hence, although there is a welter of circumstantial information, the parameters have not yet been properly established for the following aspects:-

- expected pattern of casualties by severity of injury
- proportions of different types of injuries
- relationship between building characteristics and human survival rates
- how people react to the destructive shaking of buildings that they inhabit
- likelihood of entrapment and subsequent rescue
- injury pattern in relation to entrapment in collapsed structures
- the role of field hospitals and their capacity needs
- mental health needs related to seismic disasters, including those related to the Canterbury experiences of a year and a half of repeated, damaging earthquakes.

One particular aspect that is poorly understood is the role of self-protective behaviour in saving lives. There are essentially five levels of risk to people, in relation to seismic damage levels (Alexander 2012).

1. Damage level: [1] minimum damage to walls, fitments and furniture.
   Personal risk level: prudent behaviour will minimise risks.
2. Damage level: [2] significant damage to structures, cladding and fitments.
   Personal risk level: significant risk of injury but not of death.
3. Damage level: [3] general damage and collapse of architectural elements.
   Personal risk level: significant risk of injury but relatively low risk of death.
4. Damage level: [4] serious damage or partial collapse of building.
   Personal risk level: strong risk of injury and significant risk of death.
5. Damage level: [5] collapse of more than 50% of the structure.
   Personal risk level: limited and unpredictable probability of survival.

Research tends to suggest that in a given area there are very few characteristic patterns of building failure in an earthquake. Two or three archetypical models may be sufficient to characterise the performance of vernacular housing. For instance, in the L'Aquila (central Italy) earthquake of 6 April 2009 (308 dead; 1,500 injured, of whom 202 critically) the reinforced concrete condominiums that typified housing in L'Aquila city tended to suffer from mid-floor failure caused by lack of stiffness in their frames, which allowed bottom-floor acceleration to interact with top-floor inertia (this was also observed, for example, in Mexico City in 1985). Where it occurred, collapse therefore began at the mid-floor level (Figure 1). Although virtually nothing could be done to protect people against damage level 5, strategies could be employed to help them manage levels 1-4, with the last of these, level 4, being the critical one for which self-protective behaviour would presumably have the greatest effect (Alexander 2011a).

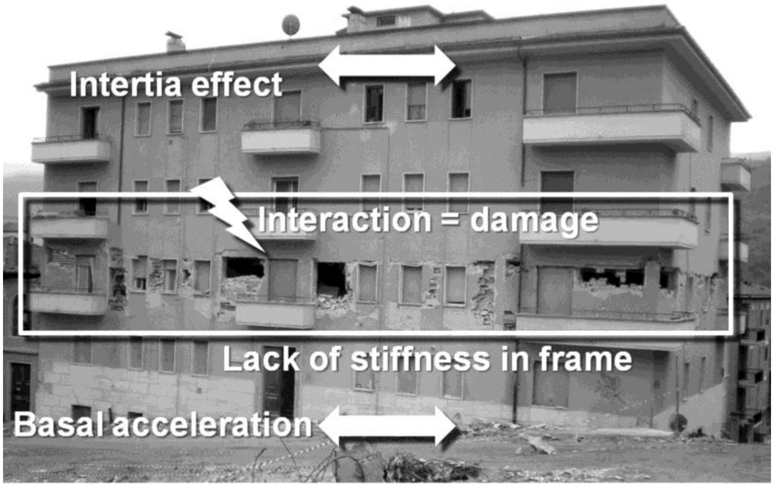

Figure 1. Characteristic pattern of incipient building failure in L'Aquila city during the 6 April 2009 M=6.3 earthquake.

An appropriate strategy would be as follows:-

- create simple models of the seismic performance of typical vernacular buildings in an area that is at risk of damaging earthquakes
- make a simple analysis of characteristic failure modes
- determine the most appropriate crisis behaviour
- educate and train residents to be familiar with the best options for self protection during an earthquake.

Research determined that in the L'Aquila earthquake it was highly risky to run out of buildings, as façade details and stairways collapsed abundantly, and in cases of partial collapse the best strategy was to retreat into the building (Alexander 2011a).

Although "drop, cover and hold" (ECAA 2008[2]) is good advice on how to behave in earthquakes, it is neither sufficient nor universally appropriate. Survival strategies need to be worked out. These can then be communicated to residents and building users, who should be encouraged to plan for an emergency situation. The survival strategy could consist of the following parts.

1. Identify the safest part of the house with regard to the following risks:-
    - fall of tiles or collapse of the entire roof
    - collapse of chimneys (including through the roof)
    - failures and falls of non-structural elements (such as light fittings, air conditioning, water tanks and heavy furniture)
    - instability of the façade and cornices
    - potential collapse of external walls (infill and cladding of r/c buildings, angles of masonry buildings)
    - potential collapse of the stairs during egress
    - detachment of beams and the risk that they will batter down the building
    - use of heterogeneous materials giving rise to a complex seismic response.
2. Avoid risky and imprudent behaviour.
3. Create an exit strategy:-
    - identify a safe place to assemble near the house
    - identify the most dangerous parts of the house and how to avoid them.
4. Create a mutual support network of friends, relatives and neighbours.
5. Collect and store useful equipment:-
    - train family members and test the action plan.

In some respects, the bank of evidence on which to base practice is least complete with regard to survival probabilities and self-protective behaviour in earthquakes. Yet it is a problem that has attracted researchers since the 1970s (Glass *et al.* 1977), and it has the potential to reduce death and injury tolls.

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[2] http://www.getthru.govt.nz/web/GetThru.nsf/web/BOWN-7GY5TP?OpenDocument

One critical aspect of post-earthquake survival is the rapidity with which rescue occurs. In countries such as New Zealand or the United States that have well-developed search-and-rescue services, help is likely to arrive during the window of survival, which is in the range 6-12 hours. Although people can survive for 14-15 days after an earthquake, statistically few of them do so. For example, in the Haiti earthquake of January 2010, only 134 people were rescued at all, despite a phenomenally high toll of casualties, and only nine of them were rescued after the fourth day (Comfort *et al.* 2011).

The international community sends between 1,200 and 2,300 foreign rescuers in teams to major earthquake disasters, and they tend to arrive between 36 and 72 hours after the disaster. Hence, very few people are rescued, and the cost is somewhere near US$1 million per life saved. It could be reduced dramatically and the number of people saved could be increased substantially by developing, funding and supporting urban search and rescue capabilities (including rapid deployment logistics and localised critical care) in major earthquake risk areas that currently lack such services (Katoch 2006).

Having considered the personal dimension of resilience, it is now appropriate to put the emphasis more firmly on the built environment and make a few observations about the seismic performance of critical infrastructure, including schools and hospitals.

3 WHAT IS CRITICAL ABOUT CRITICAL INFRASTRUCTURE?

Earthquakes cause widespread destruction that in almost all cases selectively affects particularly vulnerable assets. A second level of destruction is that which compromises the ability of the assets to function together in order to provide vital services. Infrastructure is defined as the basic facilities, services, and installations that are needed to ensure the functioning of a community or of society. Those which are regarded as critical can be listed as telecommunications, electrical power systems, gas and oil storage and transportation facilities, banking and finance, transport systems, water supply systems, hospitals, emergency services (including medical, police, fire, and rescue services) and facilities which ensure the continuity of government. However, much depends on context. For example, not every bridge in a country is critical, but the loss of one at a strategic location may prevent the delivery of vital supplies and services (Egan 2007).

The concept of critical infrastructure protection has largely been developed in relation to intentional threats, as it is assumed that the worst damage (including cyber terrorism) comes from attack rather than the more impartial depredations caused by natural disaster (Boin and McConnell 2007). Attention is also given to the question of spontaneous failure of critical infrastructure, such as the "domino-effect" of progressive, self-protective shutdown of the electricity grid as a result of a malfunction at a crucial point in the network (Sarriegi *et al*. 2008).

So far, studies have tended to show that in most places critical infrastructure is resilient to earthquakes and has the capacity to recover from them quite quickly (Kates and Pijawka 1977, Boin and McConnell 2007). But despite the lack of emphasis on seismic damage to critical infrastructure, there are some key problems in this area. Resilience is dependent on adaptability, which is itself a function of having a progressive and flexible attitude towards situations that require the ability to adapt to rapidly changing circumstances. Adaptability, and therefore resilience, is increasingly dependent on redundancy. For instance, the Internet tends to be resilient because it has a high degree of redundancy; yet damage to key fibre-optic cables has occasionally caused significant loss of traffic or slowdown in Internet connections, which shows that redundancy in the network is reduced by the presence of bottlenecks (Daskapan *et al*. 2006). Moreover, redundancy is expensive and hard to justify in terms of daily operations. If criticality cannot be demonstrated with respect to the need for redundancy (usually by reference to a basis of accumulated evidence), then expenditure may never occur. In addition, redundancy is needed, not merely in terms of the operation of single systems and subsystems, but also to guarantee critical interactions between individual systems. One of the most basic examples is the relationship between water supply and waste-water removal and treatment, which has long occupied technicians who must grapple with the complex problems of restoring both systems when they are damaged by earthquakes (Casson *et al*. 2011), but there are many even more complex examples.

It is common and traditional when planning recovery from earthquakes to emphasise the rebuilding of individual structures. In many cases, the functionality of these buildings, and hence their role in recovery, is reduced by their lack of synergy with the recovery of damaged critical infrastructure. It is therefore essential to avoid a recovery strategy based on "cathedrals in the desert" and focus on one that restores the full functionality and interconnectedness of structures. Full system recovery will facilitate commerce and the recovery of livelihoods, which are both essential to local autonomy and economic health. If this is too expensive to achieve on a comprehensive basis across the affected area then a modular strategy is recommended, in which recovery is achieved precinct by precinct, such that urban-economic functionality spreads across the area.

As an afterword, there has been an intensification of interest in the critical infrastructure problem as a result of the Great Eastern Japan Earthquake and Tsunami of 11 March 2011, the Tōhoku event, or GEJET. This focussed the world's attention on cascading disasters, in which one malfunction or set of damage leads to another. In fact, the combination of a magnitude 9 earthquake, a tsunami with waves up to 30 metres high, and meltdown and radiation release from the Fukushima nuclear generating plant represents one of the worst cases of a na-tech event, or natural-technological disaster. GEJET also redefined magnitude-frequency relations in seismic design and planning terms (Davis *et al.* 2012). As most risk to critical infrastructure involves interactions or network effects, it is central to the question of how to understand and deal with cascading disasters.

3.1 **Hospitals**

It is a paradox that hospitals are key elements of critical infrastructure in earthquakes but they are often among the most vulnerable structures (Figure 2).

Figure 2. Damage to the main hospital in Padang, Indonesia, after the 30 September 2009 Western Sumatra (M = 7.6) earthquake.

Reitherman (2004) graphically chronicled the shortcomings of hospitals affected by the 1971 San Fernando Valley (California) earthquake (M = 6.6):-

> "Of the 58 fatalities caused by building damage, 50 occurred in hospitals. The worst damage to medical facilities occurred at the Veterans Administration Hospital in Sylmar where two large buildings collapsed. Even though the hospital site was right on the edge of the heavily urbanized San Fernando Valley, it took one hour and 22 minutes before a fire department helicopter happened to spot the collapses and send help. The reason for such a delay? The phones didn’t work, the hospital’s radio was in one of the collapsed buildings, and the first message orally delivered by a hospital staff member to a nearby government facility was confused with an already received report of damage to a different nearby hospital."

No doubt the lesson has been learned in Sylmar, but the problems described have persisted elsewhere. For example, patterns of damage to medical facilities were remarkably similar in the El Salvador earthquakes of 1986 and 2001 (Wisner 2001).

The ability of medical centres to cope with influxes of earthquake casualties is thus limited by any damage and loss of functionality that they sustain. In one hospital affected by the Northridge (California) earthquake of January 1994 (M = 6.7), medical records were thrown from shelves onto the floor and saturated by water from a burst pipe, just as patients were arriving in extraordinarily large numbers and demanding to be treated (Chavez and Binder 1996). Hospital capacity should not be measured in terms of numbers of beds, as that is an expandable quantity. Key questions are as follows:-

- Can patients and essential staff reach the hospital during the emergency isolation phase immediately after an earthquake: are critical route ways open and is transportation available?
- Is diagnostic and treatment (i.e. operating) capacity sufficient?
- Are supplies of consumable goods and essential pharmaceuticals sufficient and capable of being maintained?
- Are essential systems within the hospital fully functional (utilities and distribution of medical gases)?
- How long will generators operate without fuel replenishment?
- Are key personnel fully accessible and in position?
- Is there a system-wide medical emergency plan that provides for the interaction between medical facilities (for example for the transfer of patients)?

Experience suggests that a negative answer to any one of these questions can reduce hospital capacity to a disproportionate extent during the post-earthquake surge in demand (Adini *et al.* 2006). Moreover, emergency plans should be able to cope with internal emergencies (e.g. on-site structural damage), external crises (i.e. surges in demand for treatment) and system-wide needs (e.g. inter-hospital communications and transfers). Experience also suggests that campus-type hospitals which have their facilities distributed among different buildings on the site are less vulnerable than those which consist of a single large building. In any case, all of the questions listed above can be dealt with in a pre-emptive manner by the construction of local earthquake scenarios that enable planners to anticipate needs and fulfil them in advance (Perry *et al.* 2011).

3.2 Schools

Although schools are not usually treated as elements of critical infrastructure, they nevertheless have a key role in what happens during and after an earthquake. The destruction of 230 unreinforced masonry school buildings in the Long Beach, California, earthquake of 1933 (M = 6.2) led to the Field Act for the engineering seismic safety of school buildings, which was passed exactly one month after the disaster (Olson 2003). However, high levels of vulnerability persisted for decades in schools in the other six seismic zones of the USA. In the 2001 Gujarat earthquake, which occurred at 08:45 hrs in the morning, a significant portion of the mortality was derived from schools (Sharma 2001). In the 2005 Pakistan earthquake, 17,000 children were killed in the collapse of 10,000 schools (Halvorson and Hamilton 2010). The Boumerdes earthquake of 2003 in Algeria involved the collapse of 103 schools, serious damage to 753 and damage or other effects to 2,160 (Meslem *et al.* 2012). In the Bingöl earthquake of 2003 in Turkey, almost half of the 176 fatalities came from the collapse of a school dormitory in which children were sleeping. In Italy, the earthquake of 2002 at San Giuliano di Puglia caused the deaths of 25 small children and three teachers when a school collapsed (Langenbach and Dusi 2004). This led to a review of seismic safety in all of the country's 60,000 schools. Some 18,000 of them were found to be at risk, 6,000 of these seriously, but the funds were available to start retrofitting only 2,000 schools. Meanwhile, in China, the Wenchuan earthquake of 12 May 2008 killed up to 500 children and students in the collapse of one single school (He *et al.* 2011). All of this adds up to a risk to large numbers of children that varies from negligible when schools are unoccupied to critical when vulnerable educational institutions in highly seismic areas are in use. It also involves the potential loss of key public buildings and disruption to vital educational programmes.

Children have a right to be educated, and to receive their education in conditions of safety. Moreover, they have a need and right to be protected by adults. It is clear that the first element of earthquake safety in a school is the engineering performance of the building under predictable conditions of seismic loading. However, that is not all. In ensuring the safety of school pupils and students, and the adults who work with them, there is a critical need to pay attention to the interaction between occupants and their immediate surroundings, as well as with the buildings and external environments. The standard advice to "drop, cover and hold on" when an earthquake occurs has been widely disseminated, for example, in the Great California Shakeout of November 2008, which involved more than five million members of the public (ECAA 2008). It is sensible, in that there are few viable alternatives during strong motion. However, it takes no account of the fact that the hazards posed by buildings and their fitments and contents vary from place to place—even from room to room.

School evacuation is not quite as simple as it is often portrayed. First of all, school staff members are *in loco parentis* until children can be restored to their families. Secondly, risks are associated with different strategies, for example, if flights of stairs are unstable, the ground is strewn with broken glass or heavy furniture has toppled over. There may be other hazards outside the building and problems of finding alternative accommodation and transport home. Schools are also particularly susceptible to the convergence reaction as worried parents flock to them to recover their offspring. Hence, school emergency planning requires a thorough and systematic approach—there are at least 20 steps in it—yet relatively few teachers and principals are willing to invest the time and effort in such an initiative, and relatively little guidance is available (Alexander 2002a).

Work with schoolchildren has consistently shown that they are receptive to ideas about earthquake protection and free from many of the preconceptions held by older people (Hosseini and Izadkhah 2006). Children bring notions of emergency preparedness into their families and are thus good catalysts for participatory disaster risk reduction. When children are killed and injured at school in earthquakes, the emotional effect is usually very large and it can lead to substantial reactions in favour of greater safety. For example, the deaths of 25 small children at San Giuliano di Puglia in Italy triggered a review of seismic safety in schools in Vancouver and Seattle on the other side of the world (Langenbach and Dusi 2004).

Lastly, it is as well to remember that many schools are strategic buildings that are used by their local communities. If they survive an earthquake well, they may become temporary mass shelters for people who have lost their homes. Moreover, in some countries, including New Zealand, schools may also be the local Civil Defence Centre for community-level responses.

In hospitals the onus should be on improving both the structural safety of buildings and the functional resilience of what goes on in them. In schools structural safety is also paramount, but an equally important need is to plan for the protection of occupants both during the earthquake and in the isolation period of the aftermath: it was estimated that if the Northridge (California) earthquake had occurred two hours later, and children had been sent home from school, 6,400 of them might have found no parents there to take care of them (Tierney 1994). Worldwide, the attitude to emergency planning in schools is remarkably inconsistent and, one suspects, generally rather dismissive.

4 NEGLECTED ASPECTS OF SEISMIC RISK MITIGATION PLANNING

At least the problems of creating seismic resilience in the medical and educational systems are well known and widely debated. However, there are several aspects of earthquake mitigation planning that are roundly neglected. This section will briefly discuss three of them: minorities, cultural heritage and animal health.

To begin with, most emergency planning is centred upon standardised aggregations of people and does not pay specific attention either to individuals or to groups that have special needs. It is thus common to find that individuals and minority groups are excluded from civil protection programmes. Studies in Tokyo discovered that homeless "down and outs" were not taken into account in emergency provisions and would be ignored when disaster struck (Wisner 1998). Gender discrimination in disaster was analysed in a classic paper by Rivers (1982) but since then it has proliferated rather than diminished. Nonetheless, gender equality has been identified as one of the key issues in recovery from disaster (Enarson 2012).

Some 16-20 per cent of people in society are handicapped, including large numbers of frail, vulnerable elderly citizens. Much emergency planning fails to take their needs as individuals into consideration, and hence they suffer discrimination and threats to their personal safety and well being that people who are not handicapped may never have to face. There are many different forms of handicap, involving difficulties of perception, cognition, mobility and dependence on personnel or equipment for support. In order to ensure that the rights of the disabled are maintained in disaster, emergency planning and management require a focus on the individual, not the group. This is especially true as the disadvantage that disabled people face in daily life may make them poor and vulnerable even in the absence of disaster, which can exacerbate such problems (Alexander 2011b). Studies suggest that awareness of the issues tends to be low among emergency planners, but it could be increased and procedures could be activated to redress the balance to favour the protection of the handicapped against disaster (White et al. 2004).

The handicapped are a heterogeneous class of people that interfaces with other disadvantaged groups. Evidence is emerging that single mothers, gay people, and drug addicts are among those who suffer unfair discrimination during the rationing of scarce resources after disaster (Henkel *et al.* 2006). Another group that is particularly at risk is prisoners. Evidence is mounting that with regard to disaster risk unsafe premises, unduly repressive procedures and lack of planning for contingencies threatens the inmates of prisons to a particular degree (ACLU 2006). Whatever their crimes (and in places where democracy is weak or absent not all prisoners are criminals), inmates have human rights that should not be infringed by seismic disaster, and an earthquake emergency should not be used as an excuse for repression. Once again, proper contingency planning is the answer.

Emergency planning for cultural heritage is a remarkably undeveloped field, and yet it is of enormous importance. The destruction caused by earthquakes can lead to the loss of priceless artefacts and can result in irreparable damage to revered sites. It can damage the *genius loci*, or spirit of place, a phenomenon that ties people to the localities they inhabit and is a major reason why they do not abandon them after damage has caused so much radical alteration to familiar landmarks (Alexander 1989).

Various events have led to surges of interest in the protection of cultural heritage, among them the looting of the archaeological museum in Baghdad, the destruction of the Buddha statues in Afghanistan and the shelling of historic towns during the Balkan wars of the 1990s. However, the interest has been neither sustained nor systematic (Crue and Clark 2010).

Cultural heritage is a remarkably diverse phenomenon (Goldewijk *et al.* 2011). Artefacts may consist of paper, papyrus, ceramics, glass, metal, stone, leather, hide, parchment, bone, wood, hair, horn, ivory, shell, photographic film, magnetic media, paintings on canvas or wood, sculptures, bas reliefs, fabrics or clothing. All of these have different protection and conservation needs. The main categories of cultural heritage are works of art, architecture, museums, galleries, highly prized landscapes, archaeological sites, libraries, archives, and storage facilities. As in the previous list, the categories are not necessarily mutually exclusive. Again, the conservation and protection needs are remarkably diverse.

Earthquakes can be extremely destructive to fragile items of cultural heritage. For example, the 1997 sequence of earthquakes that occurred in Umbria and Marche regions, central Italy, severely damaged 1,200 historic churches and religious institutions. Although no single shock was greater than magnitude 5.6, the cumulative effect of three months of tremors was devastating. Moreover, restoration can be a hugely expensive, long drawn-out and extremely delicate operation.

According to the International Council on Monuments and Sites (ICOMOS), no historic building need be demolished because it is vulnerable to disasters (Bumbaru 2007). However, the cost of retrofitting it may be prohibitive, the risks it sustains may be excessive, and the technical issues associated with rehabilitating it may be extremely challenging. Nevertheless, much more could be achieved, and not necessarily with excessive costs, if some standard methodologies for emergency planning and risk mitigation were more widely disseminated and used in the heritage professions, where in many cases they are utterly unknown.

Veterinary contingencies encompass the health of pets, livestock and wildlife (Dorn *et al.* 1997). All three can be disproportionately affected by disaster, yet the literature on veterinary emergency management is remarkably small. Regardless of this, the need for intervention is manifest. In Western societies many people will not evacuate their homes unless they can rescue and take with them their domestic pets. On the other hand, exotic animals may not only be left behind but may be released into the environment, creating a hazard to the public.

Livestock represent the economic security of many of the world's poorest families and any strategy for providing shelter and recovery will not work unless it takes into account their central importance in family life and economy. Even in societies where industrial-scale husbandry is the norm, earthquakes can cause a crisis in animal management, and, when the worst contingencies occur, mass mortality among farm animals poses a problem of how to dispose of the carcasses safely. Moreover, the local and regional food supply may be affected and recovery of the farm sector may depend on restoring animal health and stock numbers. Disruption of wildlife can lead to increased risk to humans. Apart from problems such as snakebites and rabies, the risk of zoonosis may be increased. We may therefore conclude that more attention should be given to veterinary emergency planning, and it should be more securely integrated into general strategies designed to cope with the impact of earthquakes (Heath 1999).

These three examples—minorities, cultural heritage and veterinary issues—may not define the problems of planning to manage earthquake disasters and reduce the risks, but they are diagnostic of a failure to learn lessons and take account of all significant eventualities. Before reaching a conclusion on these issues, we will briefly consider the need to maintain and increase resilience during the recovery and reconstruction periods.

5 RESILIENCE AND RECOVERY

Recovery from a major seismic disaster may take between ten and 25 years to accomplish (Cheng and Wang 1996). Indeed, in some instances it may never fully occur, as is the case with Nicaragua after the 1972 earthquake (Bolin and Bolton 1983). Evidence is mounting that recovery is dependent on maintaining the buoyancy of the local economy, or relaunching it (e.g. Dahlhamer and Tierney 1998). The key to individual recovery rests in the maintenance of livelihoods such that employment is a crucial issue and it needs to be vested in economic activities that will be sustained after the 'boom' of the recovery has finished—i.e. not merely in the construction industry (Alexander *et al.* 2006).

Resilience is, of course, a general problem that is not limited to the ability to face down disaster (Davidson 2010). Resource security, post-peak oil energy usage, global change, climate change, sea-level rise impacts, food security, waste management, chronic pollution, social instability, economic inequality, and global and regional conflict are all matters that need to be resolved. Hence resilience in the face of disasters must interact with these other issues (Labadie 2011). Disaster risk reduction is thus a branch of general societal resilience and cannot be achieved unless the other aspects of the problem are tackled.

It has long been known that recovery from disaster is slowed down by any failure to resolve the other resilience issues; for example, inequality and marginalisation (Cannon and Müller-Mahn 2010). Recovery and resistance to disaster risk necessitate the merging of resilience agendas, so that social and environmental extremes are tackled in comprehensive, holistic ways. One aspect of this is to make disaster response resilient (Murphy 2007). In a recession, programmes tend to be cut and progress can be annulled and transformed into backsliding such that gains in security are cancelled out amid the desire to save money. Moreover, disaster risk reduction may cease to be a political priority. To keep it on the agenda, it must be treated as a fundamental everyday service that is divided between risk management in times of seismic peace and emergency management in times of crisis. It must have the support of the population (Alexander 2012). This may require a change in culture so that disaster risk in seismic zones is treated as a more immediate, less abstract problem to be tackled seriously by constant improvements in safety. In most places threatened by earthquake such a change will require much patient and persistent work on public perceptions and opinions, sustained over a long period of decades, and assisted by an “all hazards” approach, not merely focussed on earthquake.

6 CONCLUSIONS

The history of earthquakes and the academic record of studying them are rich in lessons for seismic preparedness (Alexander 2002b). If those lessons were consistently identified, acted upon and translated into practical action, then the result would be a high level of seismic disaster risk reduction. As there is a high potential for a disaster as large as, or larger than, any seen in the last 100 years, then this need is endowed with a certain sense of imperative, but do we really learn lessons? Many reports and papers have the phrase 'lessons learned' in their titles (e.g. Rahardjo *et al.* 2008). However, the test of a lesson learned is in the mitigation actions that take place as a result of acknowledging its existence. Too many lessons are archived and forgotten, or simply ignored, hence the tendency of seismic vulnerability to reproduce itself in remarkably similar ways in widely diverse parts of the world.

There is a distinction between individual and organisational learning. As disaster risk reduction is a social activity, emphasis should be placed on the latter. Organisational learning theory is a sub-discipline of management science that has existed for slightly more than two decades (Huber 1991). It teaches us that organisations learn through varied mechanisms and in response to both external and internal stimuli (Lam 2000). In this paper I have argued that we need to refine the basis of data and information that we use to have a better evidence-based approach to seismic disaster risk reduction. Clearly, there is not merely a need to have a better basis of evidence, but also a more robust way of learning from it and translating it into mitigation actions. Much of what has been learned has come from the negative experience of coping badly with highly damaging seismic events. More ought to be learned by encouraging broader contemplation of the issues: earthquake scenario building, the acquisition of greater redundancy in protective mechanisms, attainment of a culture of protection, greater socialisation of the issues, and development of sustainable approaches that stand the test of time and are not eroded by complacency.

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