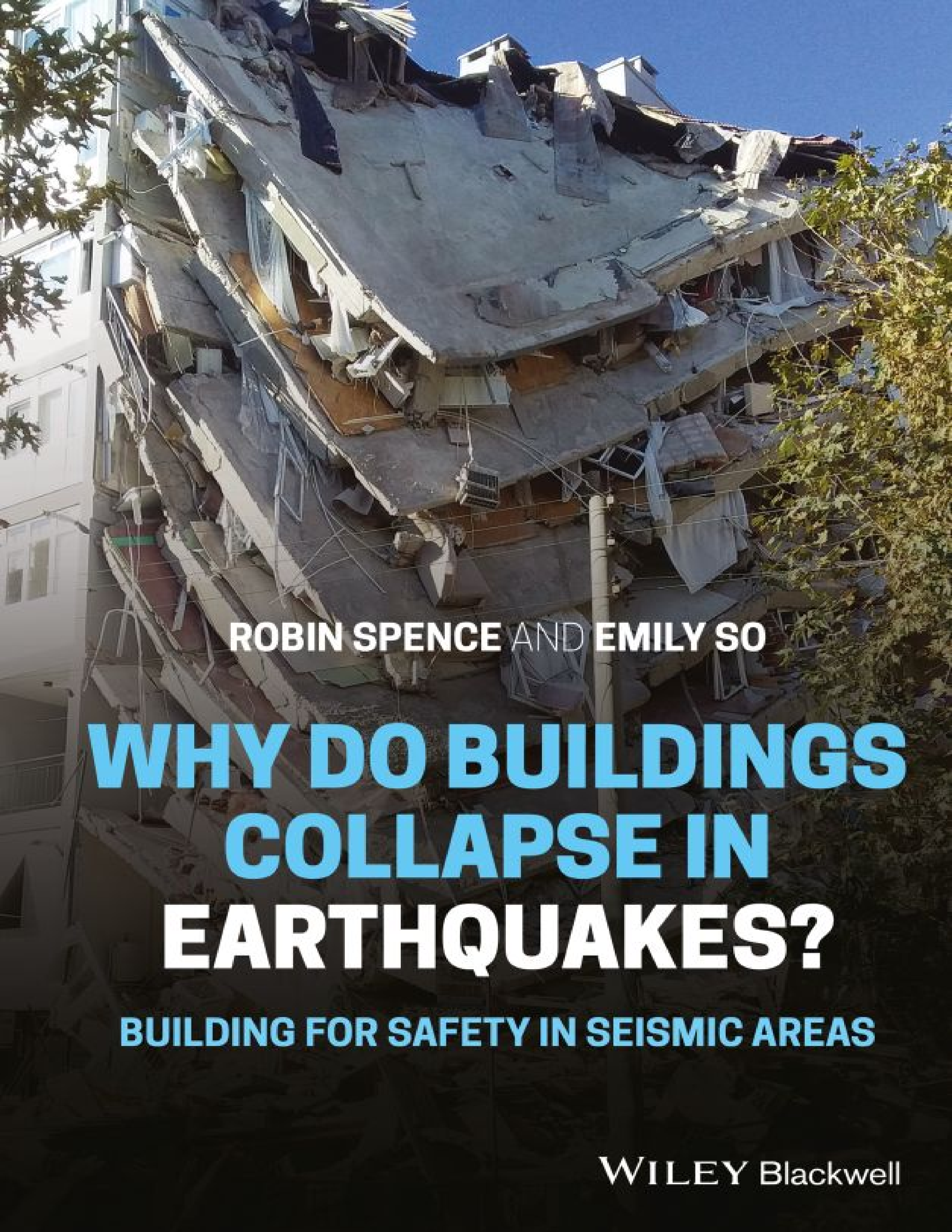

ROBIN SPENCE AND EMILY SO

WHY DO BUILDINGS COLLAPSE IN EARTHQUAKES?

BUILDING FOR SAFETY IN SEISMIC AREAS

WILEY Blackwell

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1
Introduction: Why This Book

1.1 Earthquakes – An Underrated Hazard

Earthquakes have been a threat to human habitation throughout history, but until relatively recently, their causes were poorly understood. In the pre-scientific era, they were commonly ascribed to divine intervention. By the time of the Lisbon earthquake in 1755, there were many who understood that earthquakes had natural causes, but the mechanism remained unexplained, and the supernatural explanation was widely proclaimed, especially from church pulpits (Udias and Lopez Arroyo 2009). And over 150 years later, according to observer Axel Munthe (1929), the inhabitants of Messina, destroyed by a massive M7 earthquake in 1908, cried 'Castigo di Dio' ('punishment from God').

Only with the development of plate tectonics in the twentieth century has it become understood that earthquakes are associated with active faults in the earth's crust, with most of the largest occurring at the boundaries of the tectonic plates as they interact with each other (as explained in Chapter 4). We can now identify with some precision whereabouts on the earth's surface large earthquakes will occur. From measurements of the movements at plate boundaries, and from the historical record, we can make estimates of the largest magnitude event which can occur on a fault section, and approximately, the frequency with which events of different magnitude will occur. But the largest events commonly have return periods of several centuries or more (Bilham 2009), and science is still unable to predict, even to within a few decades, when the next large earthquake on any fault section will occur.

There is some evidence that the global earthquake mortality rate (deaths per 100 000 of the world's population) has been rather gradually reducing over the last century or so. But it is a very slow rate of improvement, and the variation from decade to decade is very large. The first decade of the twenty-first century was a bad one, with several earthquakes resulting in more than 50 000 deaths. Yet, over the same timescale, death rates from many other causes, such as infectious diseases and road accidents, have been very significantly reduced (ourworldindata.org/causes-of-death 2020). This has been made possible with the introduction of public health programmes and protection measures, backed by government legislation and action programmes, but supported and implemented by the general public. Such programmes could similarly be applied to reduce earthquake risk, but in many countries most at risk, this has not so far happened. Why is this?

The greatest impact from earthquakes is nearly always the damage to buildings (and other built artefacts – roads, buildings, dams) from the ground shaking caused by the propagation of the earthquakes' waves through the earth's crust, which can result in destruction over a wide area. Over the twentieth century, understanding the nature of ground motion and the way in which this is transmitted through structures has enabled engineers to develop ways to build buildings which are able to withstand the expected ground shaking with limited damage. This understanding, gradually increasing through the development of structural engineering theory and practice, combined with detailed field investigation of the effects of successive earthquakes has enabled codes of practice for building design to be developed, and these are nowadays mandatory for new construction in most cities of the world.

But, as the world's population grows, and urbanisation increases in pace, there are many places where new buildings are being constructed without any reference to good engineering practice for earthquake resistance.

This is partly because those responsible for constructing the new buildings are unaware or possibly unconcerned that a large earthquake may occur any time soon, and building controls are lax. It is also due to lack of education, information, skill and sense of urgency on the part of builders and building owners (Bilham 2009; Moullier and Krimgold 2015).

In rural areas of many poor countries, buildings are largely constructed using highly vulnerable materials such as adobe and unreinforced masonry. Poverty and lack of understanding, combined with a vast demand for new dwelling places, are thus fuelling the creation of a series of future disaster scenarios (Musson 2012).

In order to understand why buildings collapse in earthquakes and to find out what we can do about it, we must look at each of the three ingredients of the problem: earthquakes, buildings and people.

1.2 Earthquakes, Buildings, People

One of the reasons why earthquake risk does not get acted on is because it is not well understood by the public. Although the likely locations of large earthquakes are now known, the timescale of their recurrence is very long, and for most people at risk the last occurrence of ‘the big one’ for which they need to be prepared is many centuries ago, often before the present cities existed. People may be aware that they are living in an earthquake zone but fail to appreciate the possibility of events much larger than recent experience. In 2008, a modelling exercise, the California Shakeout, was done to support earthquake protection action for Southern California, which is threatened by a large earthquake on the San Andreas Fault (Jones and Benthian 2011). Lucy Jones, who led the modelling team speaks of the ‘normalisation bias, the human inability to see beyond ourselves, so that what we experience now or in our recent memory becomes our definition of what is possible’. Seismologists had identified much greater earthquakes in the past than those in recent memory, but the last great earthquake on that section of the San Andreas Fault was in 1688. The modelling exercise, based on a plausible, but by no means worst-case scenario magnitude 7.8 earthquake on the southern section of the San Andreas Fault, showed that around 1500 buildings would collapse, and 300 000 would be severely damaged, causing around 1800 deaths and $213 billion losses. Fires would break out and could become uncontrollable. And the disruption caused to roads and pipelines would cause massive disruption to business, lasting for months. This modelling exercise led to a huge public awareness and preparation programme which has resulted in much reduced risks in California over the past decade.

But considerably more devastating consequences face many of the growing cities in other earthquake zones, particularly in Asia. The southern edge of the Eurasian Plate, stretching from the Mediterranean to China, and including Myanmar and Indonesia, is responsible for 85% of the world's historic earthquake deaths. And this is a region in which cities are today growing rapidly both in size and in number, fuelled by global population rise and urbanisation. Seismologist Roger Musson points to the risk in Tehran, today a city of 12 million people. The last major earthquake on the North Tehran Fault, passing close to the city centre, was in 1834 at a time when Tehran was a small town: an earthquake of M > 7 hitting Tehran today could cause as many as 1.4 million deaths. And seismologist Roger Bilham (2009) has estimated that a direct hit on a megacity (>10 million population) somewhere in the world once a century is now statistically probable, with a possible death toll exceeding one million, because of the combination of hazardous locations and structural vulnerability. The World Bank estimates that three billion people will live in substandard housing by 2030. By 2050, the UN projects that two-thirds of the world's population, around 7 billion people, will live in urban areas.

Unfortunately, because the threat to each city is seen as remote, protection from earthquakes is given a lower priority than other issues. Few households prioritise spending on safety from future earthquakes above pressing immediate concerns, like providing extra space or better comfort, unless required to do so by regulation. And elected governments tend to look for expenditure programmes and new regulations which will give returns within their current tenure of office, despite evidence that money spent on disaster mitigation often avoids much greater losses over time. For this reason, general development expenditure is given priority over disaster risk mitigation. And even within that part of government budgets devoted to natural disasters, those from other natural hazards are often given priority. Windstorm and flood damage are more immediate risks, particularly as these are becoming worse as a result of climate change.

Optimistically and opportunistically, the climate change agenda has provided a global focus on resilience of communities to natural threats. It is recognised that especially in developing countries, cycles of disasters have depleted decades of progress made in development. The deaths and destruction from earthquakes are preventable. Whilst the hazard itself is natural, the disasters are largely man-made, and completely preventable with proactive interventions.

1.3 The Authors' Experience of Earthquake Risk Assessment

The overall aim of our work over four decades at the University of Cambridge's Department of Architecture and at Cambridge Architectural Research Ltd has been to understand the vulnerability of buildings to earthquakes globally, in order to estimate the damage which is likely to occur from future earthquakes. This knowledge can be used to provide a sound basis to improve the building stock, and reduce damage, loss of life and disruption from future earthquakes. We have developed our knowledge of building vulnerability through a series of collaborative research projects, supported by the European Union and the UK Government and Research Councils, and through work for individual cities, companies managing portfolios of buildings and insurance companies. But the primary source of our knowledge and experience of buildings' behaviour in earthquakes has been post-earthquake field missions. We have been involved in EEFIT, the UK's Earthquake Engineering Field Investigation team, since it was founded in 1982, and have between us participated in field missions in Japan, Italy, Turkey, India, Pakistan, Peru, Indonesia, China, New Zealand and the South Pacific. The detailed nature and aims of these field missions are discussed in Chapter 2: but an essential element in all cases is to describe and document the types of building affected and the types of damage observed.

Successive projects have examined in detail the problems of particular regions. In the 1980s, we examined the traditional stone-masonry construction of rural Eastern Turkey and conducted shake-table tests in Ankara to investigate simple ways to reduce their vulnerability, the cause of many deaths in earthquakes of the previous decade. In the 1990s, we investigated the options for protecting historic European cities such as Lisbon and Naples from likely future earthquake damage, and we looked at the performance of buildings which had been strengthened following previous earthquake damage. We also developed a method for assessing human casualties from earthquakes based on the level of building damage, and with colleagues in New Zealand applied this to the city of Wellington.

Since 2000 we have worked with others to develop loss modelling approaches to estimating damage and casualties, on a city-scale (in EU collaborative projects), for insurance companies, or with the US Geological Survey, for rapid post-disaster damage assessment. And we have applied our knowledge to assist organisations with large portfolios of buildings to identify those which should be upgraded.

We have also worked with teams developing new ways to assess earthquake damage using remote sensing, and led the team developing the Earthquake Consequences Database (So et al. 2012) for the Global Earthquake Model (GEM). And we have applied similar approaches to assessing vulnerability and damage to buildings from other natural hazards such as windstorms and volcanic eruptions. All this work is described in detail in technical project reports and published papers, referred to in the chapters which follow.

1.4 Aims of This Book

The title of this book asks a question: Why do buildings collapse in earthquakes? In exploring the many layers of the answer to this question, and the many answers in differing contexts across the world, we want to demonstrate that this is not just, not even primarily, a technical question, but also a social, organisational and even political question. In this book, we look at buildings not only as assemblages of materials and components put together to achieve certain functional ends, but also as products of a society and a culture. We aim to explain the physical reasons why buildings fail to withstand earthquakes, but also to attempt to understand the social, economic and political reasons why earthquake disasters continue to happen. And through this combined understanding, we want to point to the actions that can be taken to improve seismic safety, and identify who should be taking them.

With this aim, we hope to reach a wider audience than those interested in the purely technical aspects of earthquake protection, who would prefer a non-mathematical approach to the subject, with limited technical detail. Thus, the book is designed to be read by all those interested in the consequences of earthquakes, or concerned for their own safety as occupants of buildings in earthquake areas. It is also intended for those who have responsibility for ensuring the safety of others in earthquakes, whether as government officials, political representatives, building owners or managers of businesses. The book is written for a non-technical readership, but will also be of interest to all those professionally involved in disaster preparedness and earthquake engineering, as well as to students and practitioners of architecture and engineering seeking a broad overview of the consequences of earthquakes for buildings.

Some readers of the book will live in an earthquake zone, in which case they will want to know if their homes or