SEISMIC ISOLATION FOR ARCHITECTS

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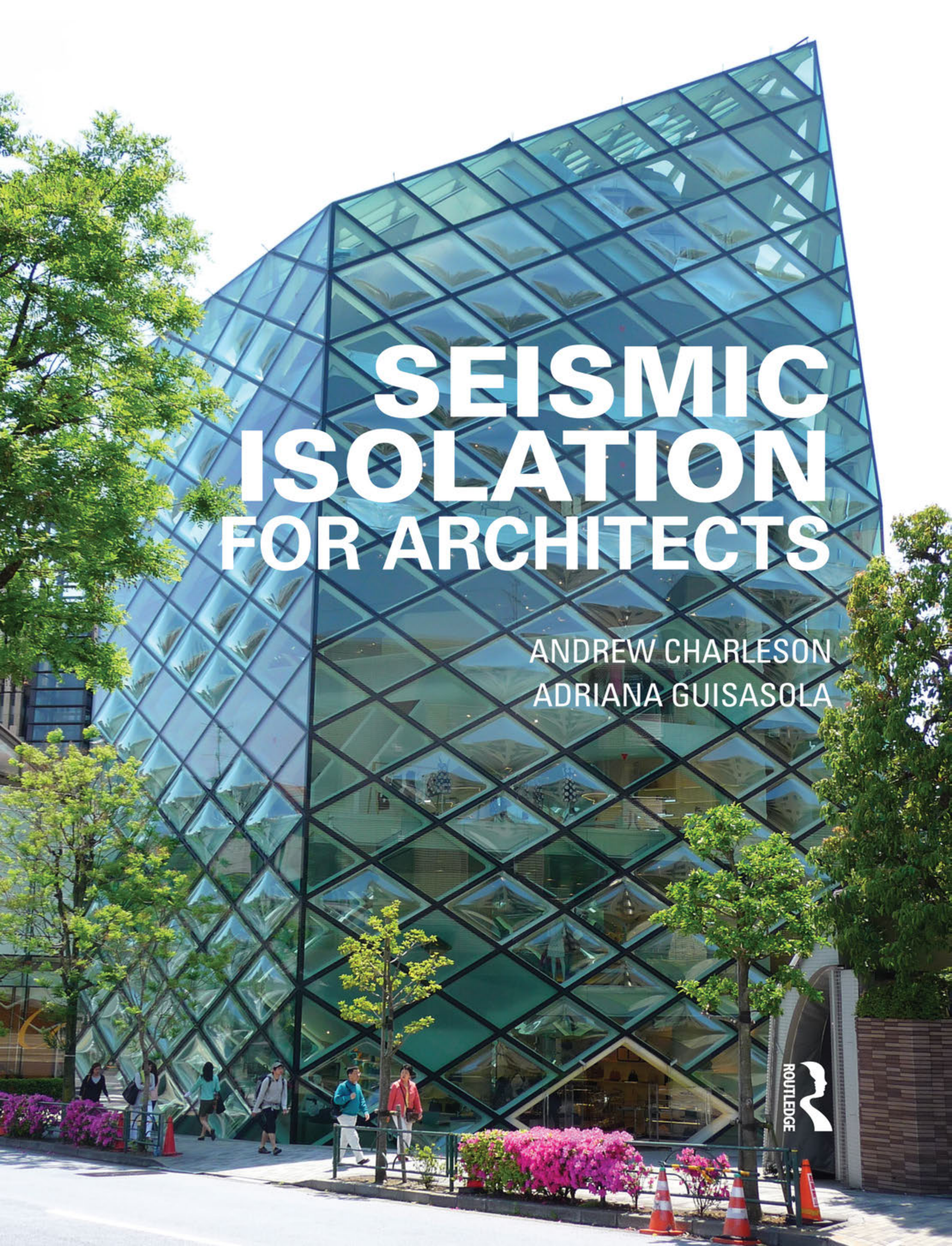

ROUTLEDGE

Seismic Isolation for Architects

Seismic isolation offers the highest degree of earthquake protection to buildings and their inhabitants. Modern applications of the technology are less than 50 years old and uptake in seismically active regions continues to soar.

Seismic Isolation for Architects is a comprehensive introduction to the theory and practice in this field. Based on the latest research findings and the authors' extensive experience, coverage includes the application, effectiveness, benefits, and limitations of seismic isolation, as well as the architectural form, design aspects, retrofitting, economics, construction, and maintenance related to this method.

The book is written for an international audience: the authors review codes and practices from a number of countries and draw on examples from 11 territories including the USA, Chile, Argentina, Italy, Japan, and New Zealand. Aimed at readers without prior knowledge of structural engineering, the book provides an accessible, non-technical approach without using equations or calculations, instead using over 200 drawings, diagrams, and images to support the text. This book is key reading for students on architecture and civil engineering courses looking for a clear introduction to seismic isolation, as well as architects and engineers working in seismically active regions.

Andrew Charleson is an Associate Professor at the School of Architecture, Victoria University of Wellington, New Zealand. A structural engineer with many years' earthquake engineering experience, he now teaches Structures. He has previously authored two books, *Seismic Design for Architects* and *Structure as Architecture.*

Adriana Guisasola is an architect and Associate Professor in Structures at the Faculty of Architecture, Urban Planning and Design, Mendoza University, Argentina. She is in the process of completing her doctoral thesis on 'Architecture and Base Isolation'. She has authored many papers for world conferences on earthquake engineering and seismic isolation, energy dissipation, and active vibration control of structures.

Between them, the authors have been actively involved in the design and construction of three seismically isolated buildings and have visited and studied over 60 more in 11 different countries.

“I believe that this very well written and documented book will be very useful to architects worldwide. In fact, it explains the features and advantages of seismic isolation in a very useful way to architects, by stressing the fact that, thanks to this technique, it is possible not only to make buildings much safer at limited additional construction costs (if any), but also to allow for adopting architectural solutions that could never be applicable to conventionally founded buildings.” – *Alessandro Martelli, President of the Italian Association GLIS, Founding President and present Vice-President of the Anti-Seismic Systems International Society (ASSISi), and former Professor of "Constructions in Seismic Areas" at the Faculty of Architecture of the University of Ferrara, Italy*

Seismic Isolation for Architects

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Introduction

Purpose and timing of the book

MANY books and articles on the seismic isolation of buildings have been written for structural engineers. However, these publications are highly technical in nature and therefore are unsuitable for the vast majority of those who design, construct, own, insure and inhabit buildings in seismically active regions. The purpose of this book, then, is to introduce a relatively new game-changing technology to a wide audience concerned about how buildings and their contents are affected by earthquakes.

A research and writing project such as this, which seeks to address all issues relevant to seismic isolation, could have been undertaken at any time over the last 35 years. Yet it would have inevitably left unanswered many important questions relevant to the seismic isolation of buildings. In particular, how confident can we be in the ability of seismic isolation to reduce damage during earthquakes, and second, how does this relatively new approach to protect buildings from earthquakes compare to more conventional ones? Is seismic isolation really worth adopting?

Within a period of 18 days ending on 11 March 2011, the answers to these questions suddenly became much clearer. On 22 February the city of Christchurch experienced a devastating earthquake located only 10 km from its centre, and at a shallow depth of 5 km. While only one base-isolated building in Christchurch, the Christchurch Women's hospital, was tested by the earthquake, so was the entire building stock of Christchurch. Hundreds of buildings, many designed in accordance with one of the world's most advanced seismic codes, survived without collapse. But tragically, for different reasons, most have subsequently been demolished. This situation raises considerable uncertainty regarding the appropriateness of modern philosophies of seismic design.

Then, on the 11 March, Japan was struck by the massive Magnitude 9 Tōhoku Earthquake, centred off the east coast. Most of the destruction was caused by the tsunami that destroyed coastal areas, but earthquake shaking damaged many buildings, and for the first time, tested hundreds of seismically isolated buildings on an unprecedented scale. Although subjected to a lesser intensity of shaking than they had been designed for, these buildings performed very well. The two earthquakes occurred within days but were located thousands of kilometres apart along the Pacific tectonic plate. Together they both demonstrated both the effectiveness of seismic isolation as well as deficiencies in current design approaches to earthquake attack, accentuating the benefits of seismic isolation.

Current approaches to the seismic design of buildings

BEFORE examining seismic isolation in detail, a primary aim of this book, we need to first explain the vulnerability of most buildings around us to earthquakes, and then explore the strengths and weaknesses of conventional as well as new structural concepts to protect buildings against earthquakes.

The buildings we inhabit tend to instil a false sense of safety, particularly with respect to earthquakes. A number of factors converge to soothe our fears about the seismic safety of a building. We note how buildings stand without any visible signs of distress. They support their self-weight plus the loads of all the equipment, stock and other contents their occupants impose. It is rare for buildings to collapse when gravity is the only force acting. We also correctly understand that the chances of an earthquake occurring during a given period of time, perhaps today or even during our lifetime, range from infinitesimal to minor. We might also believe that because the buildings around us have experienced one or more earthquakes during their lives, they can therefore be assumed safe. People who are more knowledgeable about building construction might believe that because buildings are built using modern materials of reinforced concrete or structural steel, they are safe.

Most of these perceptions are only partially correct. The reality is that the risk of a building collapsing during an earthquake is far higher than one might imagine. The unfortunate fact is that most buildings in the world, unless they have been seismically retrofitted or built since the early 1980s, are unsafe in earthquakes. In some countries even more modern buildings are at-risk. The vulnerability of unreinforced masonry buildings is well known. The undesirable combination of heavy and brittle material and a lack of strong tying between walls, and floors to walls means these buildings are usually the first to suffer earthquake damage. But what is less well known is the hazard more modern buildings pose.

It was only after the mid-1970s that codes of practice internationally rectified a critical flaw in the way buildings were designed against earthquakes. It was then that the importance of *ductility* was recognized – that ability of the structure of a building to survive earthquake over-load without collapse yet suffering damage. Although buildings designed prior to this period did possess adequate strength, for what would by today's standards be understood as small earthquakes, in many cases they will partially or fully collapse when the shaking of a large earthquake exceeds their strength (Figures 1.1 and 1.2). Rather than their structural elements such as beams, columns or structural walls bending, stretching or shearing in a *ductile* manner during a large earthquake, they break or snap suddenly, in a *brittle* way.

1.1 Example of structural damage in a building with inadequate shear walls at the garage level. Loma Prieta earthquake, San Francisco USA, 1989

Source: US Geological Survey

1.2 The seriously damaged Olive View Hospital moment frame building. San Fernando Valley earthquake, California USA, 1971

Source: National Oceanic & Atmospheric Administration (NOAA)

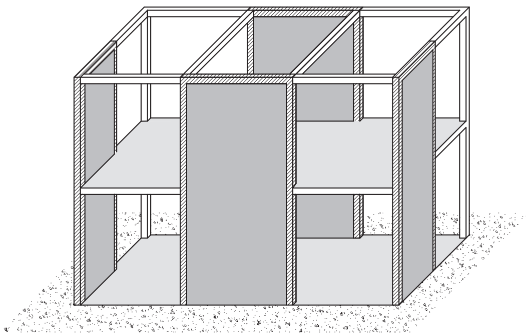
If such buildings survive a damaging earthquake without at least partial collapse, it will not be because of how the primary structural members were designed and detailed. Surviving buildings will have likely benefited from, for example, additional strength provided by walls required for fire protection along site boundaries or to confined stairwells, as well as structurally desirable characteristics such as symmetry and regularity.

Today, modern codes require that buildings avoid collapse when their primary seismic-resisting structural systems experience overload during an earthquake. And overload *is* likely given how low design load levels are where compared to loads occurring during design earthquakes. Typical modern earthquake-resistant building design begins with the selection of one of three common structural systems (Figures 1.3 and 1.4). One system will resist horizontal earthquake forces in one direction in the plan of the building, and the same or another structural system will act in the direction at 90 degrees to it. The numbers and sizes of structural members depend on many factors including the size, height and weight of the building, and the level of seismicity of the site. With strength in *both* orthogonal directions, the structure can cope with earthquake attack from *any* direction. Where parallel structural systems, such as shear walls, are separated in plan, so they don't act along the same line, they prevent the building from excessive twisting.[1] Then the structural engineer calculates the sizes and details of the structural members so that they are either so strong as not to be overloaded in an earthquake or, more commonly, designs them to be ductile. That is, even if a member is damaged it maintains most of its strength and doesn't break. But, as graphically illustrated by the Christchurch earthquake, ductility means damage which can lead to demolition.

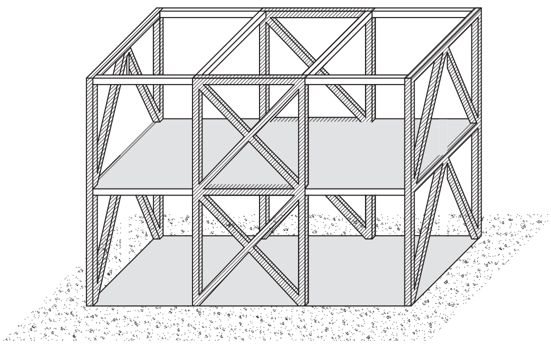
Even before the limitations of current earthquake-resistant design approaches were so starkly revealed, engineers had been developing new devices such as dampers, rather like car shock absorbers, and modifying existing structural systems to survive medium to large earthquakes with little or no structural damage. The use of dampers and 'damage-free' systems are growing in popularity, but are still uncommon (Figures 1.5 and 1.6). These new systems certainly represent a big improvement over conventional systems in which structural damage is inevitable during a large earthquake, but they are unable to offer enhanced protection for architectural elements such as claddings, interior fit outs and building contents. Seismic isolation alone protects both structure and architectural elements.

Introducing seismic isolation

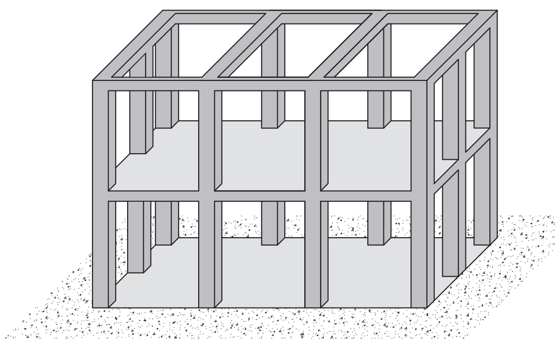
SEISMIC isolation is a term describing any sort of isolation, including by far its most common form, base isolation. Most buildings are isolated at their bases, but occasionally the isolation plane is located in a middle storey. Seismic isolation involves the partial separation of a building from the ground underneath it to reduce the intensity of the earthquake shaking it experiences. Seismic isolation is like placing the superstructure of a building on the surface of foundations that have been oiled or greased to make them slippery.



(a) Shear walls



(b) Braced frames



(c) Moment frames

1.3 The three most common structural systems for resisting horizontal forces

1.4a Example of a type of structural system: shear wall

When the most damaging earthquake waves shake the ground horizontally back and forth, the superstructure is protected by the sliding interface. If only it were that simple in practice! Rather than grease, elastomeric and or sliding bearings form the slippery isolation plane. The dynamic impact of a building superstructure against perimeter retaining walls is avoided by constructing physical separation gaps (Figure 1.7).

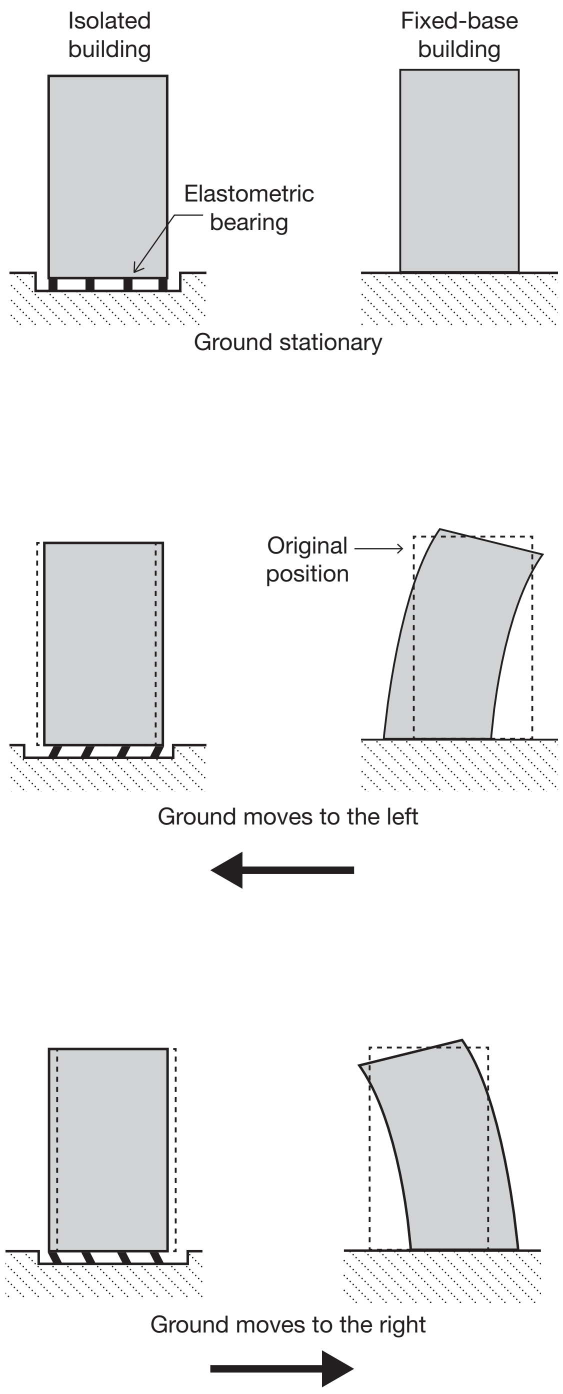
Seismically isolating a building is rather like moving a ship from a dry dock, where it is resting on the ground, and launching it into water. Once released from its foundations and floating on elastomeric or other bearings, an isolated structure is far less vulnerable to the effects of horizontal ground shaking. Usually, most of the energy of an earthquake is manifest in high frequency vibration. But since the bearings of a seismically isolated building are very flexible for horizontal movement, the building doesn't resonate like a conventional fixed-base building. Rather than experiencing violent high frequency shaking at its base, which is then amplified up its height, an isolated building enjoys a far gentler ride and an absence of increased accelerations and movement on its upper floors (Figure 1.8). Its low frequency response means less earthquake energy is transferred into the superstructure. This reduces or even eliminates damage to structural members, architectural elements and building contents as exemplified in the following two well-documented case studies.

1.4b Example of a type of structural system: single-bay moment frame

1.4c Example of a type of structural system: eccentrically braced frame

1.5 A damping device on the bottom left incorporated into cross-bracing in the National Museum of Emerging Science and Innovation, Tokyo, Japan

1.6 A damage-free structure in a hostel at Victoria University of Wellington, New Zealand. In the event of seismic overload, structural steel connections in the moment frames (along the building) and cross-braced frames (across), slip rather than break



1.7 The essence of seismic isolation. An isolated building is protected from earthquake shaking by moving at its base. Movement in a conventional building is absorbed up its height