

# GEOTECHNICAL RECONNAISSANCE OF THE 2016 $M_w$ 7.8 KAIKOURA, NEW ZEALAND EARTHQUAKE

Version 1.0: 10 JUNE 2017



## EDITORS

**Misko Cubrinovski** – QuakeCoRE (NZ) Lead; University of Canterbury, Christchurch, New Zealand  
**Jonathan D. Bray** – GEER (US) Lead; University of California, Berkeley, CA, USA

## CONTRIBUTING AUTHORS (alphabetical order)

**Sarah Bastin** – QuakeCoRE, NZ  
**Brendon A. Bradley** – University of Canterbury, Christchurch, NZ  
**Jonathan D. Bray** – University of California, Berkeley, CA, USA  
**Claudio Cappellaro** – University of Canterbury, Christchurch, NZ  
**Misko Cubrinovski** – University of Canterbury, Christchurch, New Zealand  
**Christopher de la Torre** – University of Canterbury, Christchurch, NZ  
**Russell A. Green** – Virginia Tech, Blacksburg, VA, USA  
**Christopher R. McGann** – University of Canterbury, Christchurch, NZ  
**Michael Olsen** – Oregon State University, OR, USA  
**Alessandro Palermo** – University of Canterbury, Christchurch, NZ  
**Mark Stringer** – University of Canterbury, Christchurch, NZ  
**Liam Wotherspoon** – University of Auckland, Auckland, NZ

## OTHER CONTRIBUTORS (alphabetical order)

**Jason Aricheta** – University of Auckland, Auckland, NZ  
**Adda Athanasopoulos-Zekkos** – University of Michigan, USA  
**Xavier Bellagamba** – University of Canterbury, Christchurch, NZ  
**Gabriele Chiaro** – University of Canterbury, Christchurch, NZ  
**Richard Cole** – Tonkin+Taylor, Wellington, NZ  
**Ross Davis** – Davidson Group, Blenheim, NZ  
**Kevin Foster** – University of Canterbury, Christchurch, NZ  
**Sally Hargraves** – Terra Firma Engineering, Blenheim, NZ  
**Laurie Johnson** – Laurie Johnson Consulting | Research, CA, USA  
**Maya El Kortbawi** – Virginia Tech, Blacksburg, VA, USA  
**Royce Liu** – University of Canterbury, Christchurch, NZ  
**John Manousakis** – Elxis Group, GREECE  
**Leigh McGlynn** – Davidson Group, Blenheim, NZ  
**Rebecca McMahon** – University of Auckland, Auckland, NZ  
**Matthew O'Banion** – Oregon State University, OR, USA  
**Rolando Orense** – University of Auckland, Auckland, NZ  
**Jarg Pettinga** – University of Canterbury, Christchurch, NZ  
**Emilia Stocks** – Tonkin+Taylor, Wellington, NZ  
**Sjoerd Van Ballegooy** – Tonkin + Taylor, Auckland, NZ

## **TABLE OF CONTENTS**

- i. ACKNOWLEDGEMENTS**
- 1. INTRODUCTION**
- 2. GEOLOGICAL SETTING**
- 3. STRONG GROUND MOTION OBSERVATIONS**
- 4. GEOTECHNICAL ASPECTS ON THE SOUTH ISLAND OF NEW ZEALAND**
- 5. LIQUEFACTION EFFECTS AND ASSOCIATED DAMAGE AT THE PORT OF WELLINGTON**
- 6. GEOTECHNICAL EFFECTS ON SOUTH ISLAND BRIDGES AND INFRASTRUCTURE**

## ACKNOWLEDGEMENTS

The NZ team was principally supported by the EQC Capability Grant at the University of Canterbury, and MBIE support provided for the 2016 Kaikoura Earthquake Reconnaissance. The US Geotechnical Extreme Events Reconnaissance (GEER) Association team members were supported by the National Science Foundation (NSF) through Grants CMMI-1266418 and CMMI-1724866. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF, EQC or MBIE. For more information about GEER visit: [www.geerassociation.org](http://www.geerassociation.org).

We would like to acknowledge the collaboration provided by the CentrePort Ltd. especially for allowing access to our team and making special arrangements for our multiple visits. We would also like to acknowledge the great support and collaboration from Stuart Palmer, Richard Cole, Mike Jacka, and Sjoerd van Ballegooy, from Tonkin + Taylor, who as engineers for the CentrePort provided critical input and support in various phases of these efforts. Site access assistance through Hugh Cowan of the Earthquake Commission is sincerely appreciated. Use of results from aerial survey of Thorndon Reclamation and Wharf performed by Cardno is gratefully acknowledged.

We also acknowledge the efforts of Tonkin + Taylor for developing a geospatial resource to combine the observations of the reconnaissance teams, for sharing their data and information relating to the Canterbury region, and for arranging access to the town of Kaikoura for members of the reconnaissance team. We acknowledge the Marlborough District Council for site access and allowing geotechnical information from sites within Blenheim to be shared with the reconnaissance teams.

We additionally acknowledge the support of John Wood; Michael Cowan, Jeremy Waldin and Mark Jeffries from Opus International Consultants Ltd.; and John Reynolds from NZTA for assistance, information, and insights in regard to the South Island bridges, as well as Simon Cox (GNS) for constructive feedback and comments that have been incorporated into the discussion of geotechnical aspects to the damage on the South Island.

Finally, we would like to acknowledge the collaboration of GNS Science and EERI in the coordination of the reconnaissance efforts and information sharing.

This is QuakeCoRE publication number 0187, and GEER Report Number: GEER-053.

## 1. INTRODUCTION

On November 14, 2016 at 12:02 am local time, the  $M_w$ 7.8 Kaikoura earthquake occurred along the east coast of the upper South Island, New Zealand. The fault rupture initiated in the Waiiau plains in North Canterbury and then progressed northeast. The rupture involved multiple fault segments in the region of Kaikoura and north of it. The earthquake generated intense ground shaking in the near-source region, and it caused numerous surface fault ruptures, landslides, as well as other forms of ground distress and failures, including liquefaction and lateral spreading. The earthquake affected a relatively large area along the Waiiau (North Canterbury) – Kaikoura – Blenheim (Marlborough) stretch of the South Island. It also caused considerable distress in Wellington, the capitol of New Zealand at the southern tip of the North Island. In the South Island, the most significant impacts were to a few smaller townships and rural settlements in the North Canterbury, Kaikoura, and South Marlborough regions, including residential and commercial buildings, and particularly the horizontal infrastructure in the region. In Wellington, the earthquake affected several buildings in its Central Business District (CBD) and caused liquefaction in the reclamations of port of Wellington (CentrePort), which affected wharves and buildings at the port.

Because of the large area affected by the earthquake and the different effects it produced, the geologic and geotechnical effects of the Kaikoura earthquake were documented through several independent teams who collaborated at the interfaces between their focus areas. A GNS-UC-GEER team of researchers mapped and documented surface fault ruptures and its effects, and another GNS-GEER-UC team of researchers documented the occurrence and effects of landslides. Comprehensive reconnaissance efforts were carried out by these GNS-lead efforts on surface fault rupture and landslides. The results of their reconnaissance efforts are published elsewhere.

The primary geotechnical engineering reconnaissance effort in response to the Kaikoura earthquake was conducted by a joint QuakeCoRE-GEER (NZ-US) team of researchers and engineers. The QuakeCoRE-GEER team focused on earthquake ground motions and site effects, geotechnical effects of the earthquake in Wellington (with a focus on liquefaction effects at the port of Wellington), general geotechnical effects in the South Island, geotechnical impacts on bridges and infrastructure in the South Island, and societal impacts and emergency response. The results of these geotechnical reconnaissance efforts are documented in this report.

The initial reconnaissance was performed in the period of 15 to 19 November 2016, and covered the Waiiau and Blenheim areas (but not Kaikoura itself), as well as the initial inspection of CentrePort in Wellington. Follow-on efforts from 20 November to mid-December were then organized through four teams focussing on the Waiiau area, Marlborough, Kaikoura, and CentrePort (Wellington). The majority of the observations presented in this report resulted from these reconnaissance efforts in the second half of November and early December in 2016.

The QuakeCoRE-GEER team included the following members:

Misko Cubrinovski – QuakeCore (NZ) Lead; University of Canterbury, Christchurch, New Zealand

Jonathan D. Bray – GEER (US) Lead; University of California, Berkeley, CA, USA

Sarah Bastin – QuakeCoRE, NZ

Brendon A. Bradley – University of Canterbury, Christchurch, NZ

Christopher de la Torre – University of Canterbury, Christchurch, NZ

Russell A. Green – Virginia Tech, Blacksburg, VA, USA

Christopher R. McGann – University of Canterbury, Christchurch, NZ

Michael Olsen – Oregon State University, OR, USA

Alessandro Palermo – University of Canterbury, Christchurch, NZ

Mark Stringer – University of Canterbury, Christchurch, NZ

Liam Wotherspoon – University of Auckland, Auckland, NZ

Jason Aricheta – University of Auckland, Auckland, NZ

Dan Ashfield – Tonkin + Taylor, Christchurch, NZ

Adda Athanasopoulos-Zekkos – University of Michigan, USA

Xavier Bellagamba – University of Canterbury, Christchurch, NZ

Claudio Cappellaro – University of Canterbury, Christchurch, NZ

Gabriele Chiaro – University of Canterbury, Christchurch, NZ

Ross Davis – Davidson Group, Blenheim, NZ

Kevin Foster – University of Canterbury, Christchurch, NZ

Sally Hargraves – Terra Firma Engineering, NZ

Carlo Lai – University of Pavia, Italy

Robin Lee – University of Canterbury, Christchurch, NZ

Nikolaos Ntritsos – University of Canterbury, Christchurch, NZ

Laurie Johnson – Laurie Johnson Consulting | Research, CA, USA

Maya El Kortbawi – Virginia Tech, Blacksburg, VA, USA

John Manousakis – Elxis Group, GREECE

Leigh McGlynn – Davidson Group, Blenheim, NZ

Rebecca McMahon – University of Auckland, Auckland, NZ

Matthew O'Banion – Oregon State University, OR, USA

Rolando Orense – University of Auckland, Auckland, NZ

Emilia Stocks – Tonkin+Taylor, Wellington, NZ

Jarg Pettinga – University of Canterbury, Christchurch, NZ

Sjoerd Van Ballegooy – Tonkin + Taylor, Auckland, NZ

Richard Cole – Tonkin+Taylor, Wellington, NZ

Abdul Baki – University of Canterbury, Christchurch, NZ

Royce Liu – University of Canterbury, Christchurch, NZ

Adnan Rais – University of Canterbury, Christchurch, NZ

Brandon McHaffie – University of Canterbury, Christchurch, NZ

Kaveh Andisheh – University of Canterbury, Christchurch, NZ

Roberto Gentile – University of Canterbury, Christchurch, NZ

Iolanda Nuzzo – University of Canterbury, Christchurch, NZ

Mario Granerio – University of Canterbury, Christchurch, NZ

Giuseppe Loporcaro – University of Canterbury, Christchurch, NZ

The QuakeCoRE and GEER team members worked collaboratively and shared resources, information, and logistics to conduct a thorough and efficient reconnaissance covering a large area over a limited period of time. This report summarises the key evidence and findings from the reconnaissance efforts. Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the associated organizations and funding agencies. Online versions of this report are available at the QuakeCoRE and GEER websites.

The report is organized in five chapters in addition to this introductory chapter. Chapter 2 provides the geological context for the Kaikoura Earthquake, including geologic setting, geomorphology, causative faults, and rupture characteristics of the earthquake. Chapter 3 summarizes strong ground motion observations at representative strong motion stations, and it also discusses the characteristics of the ground motions through comparisons with design spectra and empirical and physics-based ground motion models. Chapter 4 covers the geotechnical impacts of the Kaikoura Earthquake on the South Island of New Zealand, and presents key observations in three separate sections for the affected regions of Waiiau, Kaikoura, and Marlborough, respectively. Chapter 5 summarizes key observations on the performance of reclamations, wharves and buildings at the Wellington port during the Kaikoura Earthquake. Finally, Chapter 6 is focused specifically on the effects of ground shaking and ground deformation on the South Island bridges and infrastructure.