Appendix 1:
Terms of Reference

Royal Commission of Inquiry into Building Failure caused by Canterbury Earthquakes

Elizabeth the Second, by the Grace of God Queen of New Zealand and her Other Realms and Territories, Head of the Commonwealth, Defender of the Faith:

To The Honourable MARK LESLIE SMITH COOPER, of Auckland, Judge of the High Court of New Zealand; Sir RONALD POWELL CARTER, KNZM, of Auckland, Engineer and Strategic Advisor; and RICHARD COLLINGWOOD FENWICK, of Christchurch, Associate Professor of Civil Engineering:

GREETING:

## Recitals

WHEREAS the Canterbury region, including Christchurch City, suffered an earthquake on 4 September 2010 and numerous aftershocks, for example—

(a) the 26 December 2010 (or Boxing Day) aftershock; and

(b) the 22 February 2011 aftershock:

WHEREAS approximately 180 people died of injuries suffered in the 22 February 2011 aftershock, with most of those deaths caused by injuries suffered wholly or partly because of the failure of certain buildings in the Christchurch City central business district (CBD), namely the following 2 buildings:

(a) the Canterbury Television (or CTV) Building; and

(b) the Pyne Gould Corporation (or PGC) Building:

WHEREAS other buildings in the Christchurch City CBD, or in suburban commercial or residential areas in the Canterbury region, failed in the Canterbury earthquakes, causing injury and death:

WHEREAS a number of buildings in the Christchurch City CBD have been identified as unsafe to enter following the 22 February 2011 aftershock, and accordingly have been identified with a red card to prevent persons from entering them:

WHEREAS the Department of Building and Housing has begun to investigate the causes of the failure of 4 buildings in the Christchurch City CBD (the 4 specified buildings), namely the 2 buildings specified above, and the following 2 other buildings:

(a) the Forsyth Barr Building; and

(b) the Hotel Grand Chancellor Building:

WHEREAS it is desirable to inquire into the building failures in the Christchurch City CBD, to establish—

(a) why the 4 specified buildings failed severely; and

(b) why the failure of those buildings caused such extensive injury and death; and

(c) why certain buildings failed severely while others failed less severely or there was no readily perceptible failure:

WHEREAS the results of the inquiry should be available to inform decision-making on rebuilding and repair work in the Christchurch City CBD and other areas of the Canterbury region:

## Appointment and order of reference

KNOW YE that We, reposing trust and confidence in your integrity, knowledge, and ability, do, by this Our Commission, nominate, constitute, and appoint you, The Honourable MARK LESLIE SMITH COOPER, Sir RONALD POWELL CARTER, and RICHARD COLLINGWOOD FENWICK, to be a Commission to inquire into and report (making any interim or final recommendations that you think fit) upon (having regard, in the case of paragraphs (a) to (c), to the nature and severity of the Canterbury earthquakes)—

## Inquiry into sample of buildings and 4 specified buildings

(a) in relation to a reasonably representative sample of buildings in the Christchurch City CBD, including the 4 specified buildings as well as buildings that did not fail or did not fail severely in the Canterbury earthquakes—

(i) why some buildings failed severely; and

(ii) why the failure of some buildings caused extensive injury and death; and

(iii) why buildings differed in the extent to which—

(A) they failed as a result of the Canterbury earthquakes; and

(B) their failure caused injury and death; and

(iv) the nature of the land associated with the buildings inquired into under this paragraph and how it was affected by the Canterbury earthquakes; and

(v) whether there were particular features of a building (or a pattern of features) that contributed to whether a building failed, including (but not limited to) factors such as—

(A) the age of the building; and

(B) the location of the building; and

(C) the design, construction, and maintenance of the building; and

(D) the design and availability of safety features such as escape routes; and

(b) in relation to all of the buildings inquired into under paragraph (a), or a selection of them that you consider appropriate but including the 4 specified buildings,—

(i) whether those buildings (as originally designed and constructed and, if applicable, as altered and maintained) complied with earthquake-risk and other legal and best-practice requirements (if any) that were current—

(A) when those buildings were designed and constructed; and

(B) on or before 4 September 2010; and

(ii) whether, on or before 4 September 2010, those buildings had been identified as “earthquake-prone” or were the subject of required or voluntary measures (for example, alterations or strengthening) to make the buildings less susceptible to earthquake risk, and the compliance or standards they had achieved; and

(c) in relation to the buildings inquired into under paragraph (b), the nature and effectiveness of any assessment of them, and of any remedial work carried out on them, after the 4 September 2010 earthquake, or after the 26 December 2010 (or Boxing Day) aftershock, but before the 22 February 2011 aftershock; and

## Inquiry into legal and best-practice requirements

(d) the adequacy of the current legal and best-practice requirements for the design, construction, and maintenance of buildings in central business districts in New Zealand to address the known risk of earthquakes and, in particular—

(i) the extent to which the knowledge and measurement of seismic events have been used in setting legal and best-practice requirements for earthquake-risk management in respect of building design, construction, and maintenance; and

(ii) the legal requirements for buildings that are “earthquake-prone” under section 122 of the Building Act 2004 and associated regulations, including—

(A) the buildings that are, and those that should be, treated by the law as “earthquake-prone”; and

(B) the extent to which existing buildings are, and should be, required by law to meet requirements for the design, construction, and maintenance of new buildings; and

(C) the enforcement of legal requirements; and

(iii) the requirements for existing buildings that are not, as a matter of law, “earthquake-prone”, and do not meet current legal and best-practice requirements for the design, construction, and maintenance of new buildings, including whether, to what extent, and over what period they should be required to meet those requirements; and

(iv) the roles of central government, local government, the building and construction industry, and other elements of the private sector in developing and enforcing legal and best-practice requirements; and

(v) the legal and best-practice requirements for the assessment of, and for remedial work carried out on, buildings after any earthquake, having regard to lessons from the Canterbury earthquakes; and

(vi) how the matters specified in subparagraphs (i) to (v) compare with any similar matters in other countries; and

## Other incidental matters arising

(e) any other matters arising out of, or relating to, the foregoing that come to the Commission’s notice in the course of its inquiries and that it considers it should investigate:

## Matters upon or for which recommendations required

And, without limiting the order of reference set out above, We declare and direct that this Our Commission also requires you to make both interim and final recommendations upon or for—

(a) any measures necessary or desirable to prevent or minimise the failure of buildings in New Zealand due to earthquakes likely to occur during the lifetime of those buildings; and

(b) the cost of those measures; and

(c) the adequacy of legal and best-practice requirements for building design, construction, and maintenance insofar as those requirements apply to managing risks of building failure caused by earthquakes:

## Exclusions from inquiry and scope of recommendations

But, We declare that you are not, under this Our Commission, to inquire into, determine, or report in an interim or final way upon the following matters (but paragraph (b) does not limit the generality of your order of reference, or of your required recommendations):

(a) whether any questions of liability arise; and

(b) matters for which the Minister for Canterbury Earthquake Recovery, the Canterbury Earthquake Recovery Authority, or both are responsible, such as design, planning, or options for rebuilding in the Christchurch City CBD; and

(c) the role and response of any person acting under the Civil Defence Emergency Management Act 2002, or providing any emergency or recovery services or other response, after the 22 February 2011 aftershock:

## Definitions

And, We declare that, in this Our Commission, unless the context otherwise requires,—

### best-practice requirements

includes any New Zealand, overseas country’s, or international standards that are not legal requirements

### Canterbury earthquakes

means any earthquakes or aftershocks in the Canterbury region—

(a) on or after 4 September 2010; and

(b) before or on 22 February 2011

### Christchurch City CBD

means the area bounded by the following:

(a) the 4 avenues (Bealey Avenue, Fitzgerald Avenue, Moorhouse Avenue, and Deans Avenue); and

(b) Harper Avenue

### failure

in relation to a building, includes the following, regardless of their nature or level of severity:

(a) the collapse of the building; and

(b) damage to the building; and

(c) other failure of the building

### legal requirements

includes requirements of an enactment (for example, the building code):

## Appointment of chairperson

And We appoint you, The Honourable MARK LESLIE SMITH COOPER, to be the chairperson of the Commission:

## Power to adjourn

And for better enabling you to carry this Our Commission into effect, you are authorised and empowered, subject to the provisions of this Our Commission, to make and conduct any inquiry or investigation under this Our Commission in the manner and at any time and place that you think expedient, with power to adjourn from time to time and from place to place as you think fit, and so that this Our Commission will continue in force and that inquiry may at any time and place be resumed although not regularly adjourned from time to time or from place to place:

## Information and views, relevant expertise, and research

And you are directed, in carrying this Our Commission into effect, to consider whether to do, and to do if you think fit, the following:

(a) adopt procedures that facilitate the provision of information or views related to any of the matters referred to in the order of reference above; and

(b) use relevant expertise, including consultancy services and secretarial services; and

(c) conduct, where appropriate, your own research; and

(d) determine the sequence of your inquiry, having regard to the availability of the outcome of the investigation by the Department of Building and Housing and other essential information, and the need to produce an interim report:

## General provisions

And, without limiting any of your other powers to hear proceedings in private or to exclude any person from any of your proceedings, you are empowered to exclude any person from any hearing, including a hearing at which evidence is being taken, if you think it proper to do so:

And you are strictly charged and directed that you may not at any time publish or otherwise disclose, except to His Excellency the Governor-General of New Zealand in pursuance of this Our Commission or by His Excellency’s direction, the contents or purport of any interim or final report so made or to be made by you:

And it is declared that the powers conferred by this Our Commission are exercisable despite the absence at any time of any 1 member appointed by this Our Commission, so long as the Chairperson, or a member deputed by the Chairperson to act in the place of the Chairperson, and at least 1 other member, are present and concur in the exercise of the powers:

## Interim and final reporting dates

And, using all due diligence, you are required to report to His Excellency the Governor-General of New Zealand in writing under your hands as follows:

(a) not later than 11 October 2011, an interim report, with interim recommendations that inform early decision-making on rebuilding and repair work that forms part of the recovery from the Canterbury earthquakes; and

(b) not later than 11 April 2012, a final report:

And, lastly, it is declared that these presents are issued under the authority of the Letters Patent of Her Majesty Queen Elizabeth the Second constituting the office of Governor-General of New Zealand, dated 28 October 1983\*, and under the authority of and subject to the provisions of the Commissions of Inquiry Act 1908, and with the advice and consent of the Executive Council of New Zealand.

In witness whereof We have caused this Our Commission to be issued and the Seal of New Zealand to be hereunto affixed at Wellington this 11th day of April 2011.

Witness Our Trusty and Well-beloved The Right Honourable Sir Anand Satyanand, Chancellor and Principal Knight Grand Companion of Our New Zealand Order of Merit, Principal Companion of Our Service Order, Governor-General and Commander-in-Chief in and over Our Realm of New Zealand.

ANAND SATYANAND, Governor-General.

By His Excellency’s Command—

JOHN KEY, Prime Minister.

Approved in Council—

REBECCA KITTERIDGE, Clerk of the Executive Council.

*\*SR 1983/225*

## Modifications to Reporting Requirements and Powers of Royal Commission of Inquiry into Building Failure Caused by Canterbury Earthquakes

Elizabeth the Second, by the Grace of God Queen of New Zealand and her Other Realms and Territories, Head of the Commonwealth, Defender of the Faith:

To The Honourable MARK LESLIE SMITH COOPER, of Auckland, Judge of the High Court of New Zealand; Sir RONALD POWELL CARTER, KNZM, of Auckland, Engineer and Strategic Adviser; and RICHARD COLLINGWOOD FENWICK, of Christchurch, Associate Professor of Civil Engineering:

GREETING:

WHEREAS by Our Warrant, dated 11 April 2011, issued under the authority of the Letters Patent of Her Majesty Queen Elizabeth the Second constituting the office of Governor-General of New Zealand, dated 28 October 1983, and under the authority of and subject to the provisions of the Commissions of Inquiry Act 1908, and with the advice and consent of the Executive Council of New Zealand, we nominated, constituted, and appointed you, the said The Honourable MARK LESLIE SMITH COOPER, Sir RONALD POWELL CARTER, KNZM, and RICHARD COLLINGWOOD FENWICK, to be a Commission to inquire into and report (making any interim or final recommendations that you think fit) upon certain matters relating to building failure caused by the Canterbury earthquakes:

AND WHEREAS by Our said Warrant you are required to report finally to His Excellency the Governor-General of New Zealand not later than 11 April 2012:

AND WHEREAS it is expedient that the time and other requirements for reporting under Our said Warrant should be modified as hereinafter provided:

NOW, THEREFORE, We do by these presents require you to report and make final recommendations (required and otherwise) on the matters in Our said Warrant as follows:

(a) not later than 29 June 2012, on matters that would inform early decision-making on rebuilding and repair work that forms part of the recovery from the Canterbury earthquakes;

and

(b) at any time before 12 November 2012 on any other matter, if you are able to do so; and

(c) not later than 12 November 2012, on all matters on which you have not otherwise reported:

AND WHEREAS it is expedient that the powers conferred by Our said Warrant be modified, We do by these presents declare that the powers are exercisable by the Chairperson, or a member deputed by the Chairperson to act in the place of the Chairperson, despite the absence of 1 or 2 of the persons appointed to be members of the Commission, so long as at least 1 other member concurs in the exercise of the powers:

AND it is declared that nothing in these presents affects any act or thing done or decision made by the Commission or any of its members, in the exercise of its powers, before the making of these presents:

And We do hereby confirm Our Warrant dated 11 April 2011 and the Commission constituted by that Warrant, except as modified by these presents:

And, lastly, it is declared that these presents are issued under the authority of the Letters Patent of Her Majesty Queen Elizabeth the Second constituting the office of Governor-General of New Zealand, dated 28 October 1983, and under the authority of and subject to the provisions of the Commissions of Inquiry Act 1908, and with the advice and consent of the Executive Council of New Zealand.

In Witness whereof We have caused these presents to be issued and the Seal of New Zealand to be hereunto affixed at Wellington this 7th day of February 2012.

Witness Our Trusty and Well-beloved Lieutenant General The Right Honourable Sir Jerry Mateparae, Chancellor and Principal Knight Grand Companion of Our New Zealand Order of Merit, Principal Companion of Our Service Order, Governor-General and Commander-in-Chief in and over Our Realm of New Zealand.

[L.S.]

LT GEN SIR JERRY MATEPARAE, Governor-General

By His Excellency’s Command-

JOHN KEY, Prime Minister.

Approved in Council-

REBECCA KITTERIDGE, Clerk of the Executive Council.

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Appendix 2:
Expert advisers

## Expert advisers

John Berrill, Director, Canterbury Seismic Instruments

Brendon Bradley, Lecturer, Department of Civil and Natural Resources Engineering, University of Canterbury

David Brunsdon, Kestral Group, Wellington

Andrew Buchanan, Professor of Timber Design, Department of Civil and Natural Resources Engineering, University of Canterbury

Desmond Bull, Holcim Adjunct Professor in Concrete Design, Department of Civil and Natural Resources Engineering, University of Canterbury

Athol Carr, Professor Emeritus, Department of Civil and Natural Resources Engineering, University of Canterbury

Charles Clifton, Associate Professor of Civil Engineering, Department of Civil and Environmental Engineering, The University of Auckland

Compusoft Engineering Ltd, Civil, Structural and Mechanical Engineers, Auckland

Misko Cubrinovski, Associate Professor Emeritus, Department of Civil and Natural Resources Engineering, University of Canterbury

Rajesh Dhakal, Associate Professor, Department of Civil and Natural Resources Engineering, University of Canterbury

GNS Science, Wellington

Michael Griffith, Professor, Department of Civil, Environmental and Mining Engineering, University of Adelaide

John Hare, Executive Director, Holmes Consulting Ltd and President, Structural Engineering Society of New Zealand (SESOC)

Jason Ingham, Associate Professor, Department of Civil and Environmental Engineering, The University of Auckland

Institution of Professional Engineers New Zealand (IPENZ)

Ian McCahon, Principal, Geotech Consulting Ltd, Christchurch

Kevin McManus, Geotechnical Engineer, Nelson

Les Megget, Retired Senior Lecturer, Department of Civil and Environmental Engineering, The University of Auckland

Gregory MacRae, Associate Professor, Department of Civil and Natural Resources Engineering, University of Canterbury

New Zealand Society for Earthquake Engineering Inc (NZSEE)

Alessandro Palermo, Senior Lecturer, Department of Civil and Natural Resources Engineering, University of Canterbury

Stefano Pampanin, Associate Professor, Department of Civil and Natural Resources Engineering, University of Canterbury

Michael Pender, Professor, Department of Civil and Environmental Engineering, The University of Auckland

Jarg Pettinga, Professor, Department of Geological Sciences, University of Canterbury

Spencer Holmes Ltd, Civil and Structural Engineers, Wellington

Structural Engineering Society of New Zealand (SESOC)

Tonkin and Taylor Ltd, Environmental and Engineering Consultants, Christchurch

## International peer reviewers/experts

Norman Abrahamson, Adjunct Professor, Department of Civil and Environmental Engineering, University of California at Berkeley

Ralph Archuleta, Professor, Department of Earth Science, University of California at Santa Barbara

Jonathan Bray, Professor, Department of Civil and Environmental Engineering, University of California at Berkeley

William Holmes, Principal, Rutherford and Chekene, Consulting Engineers, San Francisco

Bret Lizundia, Principal, Rutherford and Chekene, Consulting Engineers, San Francisco

Fred Turner, Staff Structural Engineer, Alfred E. Alquist, Seismic Safety Commission, California

Appendix 3:
Submitters and witnesses

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| Submissions received: Seismicity |
| **Person or organisation** | **Paper/book** |
| Auckland Council | *Submission to the Canterbury Earthquakes Royal Commission by the Civil Defence Emergency Management Group/Auckland Council.* |
| Department of Building and Housing | *Department of Building and Housing submission on the GNS Science report “Canterbury Earthquakes sequence and implications for Seismic design levels.”* |
| The Royal Society of New Zealand | *The Darfield Earthquake: The value of long-term research.* |
|  | *The Canterbury Earthquakes: Scientific answers to critical questions* (co-authored with the Office of the Prime Minister’s Science Advisory Committee.) |
|  | *The Canterbury Earthquakes: Answers to critical questions about buildings.* |
| Rachael Ford and Ed Radley | *Submission to the Royal Commission: Seismic Hearing 2011.* |
| Dr David Hopkins | *The Canterbury Earthquakes: Implications for Building and Construction Standards.* |
| Ken Sibly | *Christchurch – Past, Present and Future.*Enclosures: |
|  | Clark, W. (1878). *Drainage Scheme for Christchurch and the Suburbs: With Plan, and Explanatory Diagrams.* Christchurch, New Zealand: Author. |
|  | Wilson, J. (1999*). Christchurch: Swamp to City: A Short History of the Christchurch Drainage Board*, 1875-1989. Lincoln, New Zealand: Te Waihora Press. |
| James Quinwallace | *A Scientific Understanding of the Canterbury Crustal Earthquakes: From 4 September 2010 to their Closure on 21 June 2011* and Addendum “Hysterisis Loop in Port Hills Seismic Shockwave”. |
|  | Quinwallace, J. (2011). *Love from Rolleston: The End of the Christchurch Quakes*. Christchurch, New Zealand: Jaquin Press. |
| Ross Thomson | Submissions by email on 1 September 2011 and 14 September 2011. |

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| Submissions received: Soil and ground conditions |
| **Person or organisation** | **Paper** |
| Christchurch City Council | *Submission on “Foundations on Deep Alluvial Soil” Report.* |
| Tonkin and Taylor | *Submission: Foundations on Deep Alluvial Soils.* |
| Malcolm Flain | *Submission.* |
| Dr David Hopkins | *The Canterbury Earthquakes: Implications for Building and Construction Standards.* |
| Dr Kevin McManus | *Foundation design reliability issues.* |
| Carl O’Grady | Submission by email on 16 September 2011. |
| Ken Sibly | *Christchurch – Past, Present and Future.*Enclosures:Clark, W. (1878). *Drainage Scheme for Christchurch and the Suburbs: With Plan, and Explanatory Diagrams.* Christchurch, New Zealand: Author.Map. *Christchurch Areas Showing Waterways, Swamp & Vegetation Cover in 1856: Map compiled from ‘Black Maps’ approved by J Thomas & Thomas Cass Chief Surveyors 1856.*Wilson, J. (1999). *Christchurch: Swamp to City: A Short History of the Christchurch Drainage Board, 1875-1989.* Lincoln, New Zealand: Te Waihora Press. |
| Ross Thomson | Submission by email on 20 September 2011. |
| David Penney | Submission by letter received on 1 November 2011 and by email on 23 October 2011 and 15 December 2011. |

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| Submissions received: PGC building |
| **Person or organisation** | **Paper** |
| Ken Sibly | *Submission on the PGC Building formally [sic] the Christchurch Drainage Board at 233 Cambridge Terrace.* |

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| Submissions received: Forsyth Barr and Hotel Grand Chancellor |
| **Person or organisation** | **Paper** |
| Heather Murdoch | Submission by email on 14 November 2011. |

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| Submissions received: New building technologies (low-damage technologies) |
| **Person or organisation** | **Paper** |
| Cement and Concrete Association of New Zealand | *Submission to the Royal Commission of Inquiry into Building Failure Caused by the Canterbury Earthquakes.* |
| Department of Building and Housing | *Department of Building and Housing submission to the Royal Commission for the Canterbury Earthquakes on New Building Technologies.* |
| Heavy Engineering Research Association | *HERA Submission to the October 2011 Interim Report.* |
| Precast New Zealand Incorporated | *A Submission to the Canterbury Earthquakes Royal Commission.* |
| The Royal Society of New Zealand | *The Canterbury Earthquakes: Scientific answers to critical questions* (co-authored with the Office of the Prime Minister’s Science Advisory Committee, Resubmitted. |
| Steel Construction New Zealand Incorporated | *Submission by Steel Construction New Zealand Incorporated to Canterbury Earthquakes Royal Commission.* |
| Colin Ashby | *Further Submission to the Canterbury Earthquakes Royal Commission on Base Isolation.* |
| Charles CliftonAssociate Professor of Civil Engineering,The University of Auckland | *Christchurch Earthquake Series: The Case for Structural Steel Systems.* Presentation to the Royal Commission.*Submission by letter received on 19 October 2011.* |
| Rajesh Dhakal Associate Professor, Department of Civil and Natural Resources Engineering,University of Canterbury | *Submission by email received on 26 March 2012.* |
| Trevor KellyTechnical Director,Holmes Consulting Group | *Submission by email received on 19 March 2012.* |

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| Submissions received: Structural Engineering Society New Zealand Practice Note: *Design of Conventional Structural Systems Following the Canterbury Earthquakes* *(Submitted to the Canterbury Earthquakes Royal Commission)* |
| **Person or organisation** | **Paper** |
| Aurecon | *Submission to the Royal Commission Inquiry into the Canterbury Earthquake [sic].* |
| Beca Carter Hollings and Ferner Limited | *Submission concerning SESOC Practice Note “Design of Conventional Structural Systems following the Canterbury Earthquakes.”* |
| Construction Techniques Group Limited | *Concerning: Design of Conventional Structural Systems Following the Canterbury Earthquakes.* |
| Compusoft Engineering | *Submission regarding SESOC Practice Note: Design of Conventional Structural Systems Following the Canterbury Earthquakes.* |
| Department of Building and Housing | *Department of Building and Housing Submission on the Structural Engineering Society of New Zealand (SESOC) Practice Note on the Design of Conventional Structural Systems following the Canterbury Earthquakes.* |
| Dunning Thornton Consultants | *Comments on Sesoc Practice Note: Design of Conventional Structural Systems Following the Canterbury Earthquakes.* |
| Hamilton City Council | Submission by email on 15 February 2012. |
| Standards Council | *Royal Commission of Inquiry into Building Failure Caused by the Canterbury Earthquakes: Standards Council – Submission 2.* |
| Structural Engineering Society New Zealand Incorporated | SESOC Practice Note*. Design of Conventional Structural Systems Following the Canterbury Earthquakes.* |
| Colin Ashby | *Submission to the Canterbury Earthquake Royal Commission On the Paper “Design of Conventional Structural Systems Following The Canterbury Earthquakes.”* |
| Dene CookChairman of the NZS 3101 Committee | *SESOC Practice Note – Design of Conventional Structural Systems following the Canterbury Earthquake.*  |
| Michael PenderProfessor of Geotechnical Engineering,University of Auckland | *Submission to the Canterbury Earthquakes Royal Commission re SESOC documents to the Royal Commission of September and December 2011 – Comments from Michael Pender.* |

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| Witnesses who appeared at the hearing for seismicity (17–20 October 2011) |
| **Person** | **Organisation** | **Hearing** |
| Norman Abrahamson | Adjunct Professor, Department of Civil and Environmental Engineering, University of California at Berkeley (video) | 19 October 2011 |
| Dr Kelvin Berryman | Manager, Natural Hazards Research Platform, GNS Science | 19 October 2011 |
| Rachael Ford | Interested party (video) | 18 October 2011 |
| Dr Graeme McVerry | Principal Scientist, Hazards Group, GNS Science | 18 October 2011,19 October 2011 |
| Jarg Pettinga | Professor, Department of Geological Sciences, University of Canterbury | 18 October 2011,19 October 2011 |
| Dr Terry Webb | Director, Natural Hazards Division, GNS Science | 17 October 2011,18 October 2011,19 October 2011 |

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| Witnesses who appeared at the hearing for soil and ground conditions (25 October 2011) |
| **Person** | **Organisation** | **Hearing** |
| Jonathan Bray | Professor, Department of Civil and Environmental Engineering, University of California at Berkeley (video) | 25 October 2011 |
| Ian McCahon | Principal, Geotech Consulting Limited | 25 October 2011 |
| Misko Cubrinovski | Associate Professor, Department of Civil and Natural Resources Engineering, University of Canterbury | 25 October 2011 |
| Kevin McManus | Interested party | 25 October 2011 |

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| Witnesses who appeared at the hearing for the PGC building (28 November – 6 December 2011) |
| **Person** | **Role/Organisation** | **Hearing** |
| Alistair Boys | Structural engineer, Holmes Consulting Group | 30 November 2011 |
| Howard Buchanan | Commercial Manager, NAI Harcourts | 29 November 2011 |
| Stephen Collins | Director, Cambridge 233 Ltd (building owner) | 28 November 2011 |
| Helen Golding | Tenant | 29 November 2011 |
| Helen Guiney | Perpetual (tenant) | 28 November 2011 |
| Colin Hair | Company Secretary, Pyne Gould Corporation (former owner and tenant) | 29 November 2011 |
| John Hare | Director, Holmes Consulting Group | 5 December 2011 |
| William Holmes | Rutherford & Chekene, Consulting Engineers (peer reviewed the Department of Building and Housing’s technical investigation reports for the Royal Commission) | 6 December 2011 |
| Rob Jury | Manager of Wellington Structural, Beca | 5 December 2011 |
| Stephen McCarthy | Environmental Policy and Approvals Manager, Christchurch City Council | 28 November 2011,29 November 2011 |
| Ann Cherie Manawatu-Pearcy | Senior Property Manager, NAI Harcourts | 30 November 2011 |
| Nigel Priestley | Emeritus Professor, University of California at San Diego and Emeritus Co-director of the ROSE School | 5 December 2011,6 December 2011 |
| Glenys Ryan | Education Review Office (tenant) | 28 November 2011 |
| David Sandeman | Marsh Insurance (tenant) | 28 November 2011 |
| Dr Richard Sharpe | Technical Director of Earthquake Engineering, Wellington, Beca | 5 December 2011 |
| Julia Stannius | MARAC (tenant) | 28 November 2011 |
| Louise Sutherland | Commercial Property Manager, NAI Harcourts | 29 November 2011 |
| James West | Operations and Financial Controller, Pyne Gould Corporation | 29 November 2011 |
| Mark Whiteside | Structural engineer, Holmes Consulting Group | 30 November 2011 |
| Robert Wynn | Witness to the collapse of the PGC building | 28 November 2011 |

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| Witnesses who appeared at the hearing for the Hotel Grand Chancellor (17–18 January 2010; 15 March 2012) |
| **Person** | **Organisation** | **Hearing** |
| John Hare | Director, Holmes Consulting Group | 18 January 2012 |
| Gary Haverland | Director, Structex Metro, Structex | 18 January 2012 |
| William Holmes | Principal, Rutherford & Chekene, Consulting Engineers, San Francisco (engaged by the Royal Commission to peer review the Department of Building and Housing reports) | 18 January 2012 |
| Andrew Lind | Structural Engineer, Powell Fenwick | 18 January 2012 |
| Steve Martin | General Manager, Hotel Grand Chancellor (video) | 18 January 2012 |
| Stephen McCarthy | Environmental Policy and Approvals Manager, Christchurch City Council | 18 January 2012 |
| Stefano Pampanin | Associate Professor, Department of Civil and Natural Resources Engineering, University of Canterbury (member of the Expert Panel appointed by the Department of Building and Housing) | 17 January 2012 |
| Adam Thornton | Managing Director, Dunning Thornton Consultants (author of the report on the Hotel Grand Chancellor prepared for the Department of Building and Housing) | 17 January 2012 |

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| Witnesses who appeared at the hearing for the Forsyth Barr building (23–24 February 2012) |
| **Person** | **Organisation** | **Hearing** |
| Desmond Bull | Holcim Adjunct Professor in Concrete Design, Department of Civil and Natural Resources Engineering, University of Canterbury | 24 February 2012 |
| Grant Cameron | GCA Lawyers (tenant of the Forsyth Barr building) | 23 February 2012 |
| Ewan Carr | Tenant of the Forsyth Barr building | 23 February 2012 |
| John Hare | Director, Holmes Consulting Group | 24 February 2012 |
| Rob Jury | Manager of Wellington Structural, Beca (author of the Department of Building and Housing’s technical investigation report into the Forsyth Barr stairs) | 23 February 2012 |
| Stephen McCarthy | Environmental Policy and Approvals Manager, Christchurch City Council | 23 February 2012 |
| Nigel Priestley | Emeritus Professor, University of California at San Diego and Emeritus Co-director of the ROSE School (member of the Department of Building and Housing’s Expert Panel) | 23 February 2012 |
| Dr Richard Sharpe | Technical Director of Earthquake Engineering, Wellington, Beca (author of the Department of Building and Housing’s technical investigation report into the Forsyth Barr stairs) | 23 February 2012 |
| Paul Tonkin | Site manager for the construction of the Forsyth Barr building (formerly employed by Fletcher Construction) | 24 February 2012 |

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| Witnesses who appeared at the hearing for new building technologies (12–14 March 2012) |
| **Person** | **Organisation** | **Hearing** |
| Mark Batchelar | Principal, MLB Consulting Engineers | 13 March 2012 |
| Andrew Buchanan | Professor of Timber Design, Department of Civil and Natural Resources Engineering, University of Canterbury | 13 March 2012 |
| Desmond Bull | Holcim Adjunct Professor in Concrete Design, Department of Civil and Natural Resources Engineering, University of Canterbury | 13 March 2012 |
| Andrew Charleson | Associate Professor, School of Architecture, Victoria University | 14 March 2012 |
| Charles Clifton | Associate Professor of Civil Engineering, Department of Civil and Environmental Engineering, The University of Auckland | 13 March 2012 |
| Carl Devereux | Technical Director, Aurecon Group | 13 March 2012 |
| Megan Devine | General Manager, Robinson Seismic | 12 March 2012 |
| Rajesh Dhakal | Associate Professor, Department of Civil and Natural Resources Engineering, University of Canterbury | 12 March 2012 |
| Sean Gledhill | Technical Director, Aurecon Group | 13 March 2012 |
| John Hare | Director, Holmes Consulting Group | 13 March 2012 |
| Gary Haverland | Director, Structex Metro, Structex | 13 March 2012 |
| David Kelly | Deputy Chief Executive, Building Quality, Department of Building and Housing | 14 March 2012 |
| Trevor Kelly | Technical Director, Holmes Consulting Group | 12 March 2012 |
| Stefano Pampanin | Associate Professor, Department of Civil and Natural Resources Engineering, University of Canterbury | 13 March 2012 |
| Didier Pettinga | Project Engineer, Holmes Consulting Group | 12 March 2012 |
| Nigel Priestley | Emeritus Professor, University of California at San Diego and Emeritus Co-director of the ROSE School | 12 March 2012 |
| Pierre Quenneville | Professor, Professor of Timber Design and Head of Department, Department of Civil and Environmental Engineering, The University of Auckland | 14 March 2012 |
| John Reelick | Tuakau Timber Treatment | 13 March 2012 |
| Dr Richard Sharpe | Technical Director of Earthquake Engineering, Wellington, Beca  | 12 March 2012 |
| Peter Thorby | Manager, Building Standards Group, Department of Building and Housing | 14 March 2012 |
| Trevor Watt | New Zealand Institute of Architects | 14 March 2012 |
| Grant Wilkinson | Senior design engineer, Ruamoko Solutions | 12 March 2012 |

Appendix 4:
Glossary of terms

Active link A ductile shear yielding element in an eccentrically braced steel frame.

Base isolation A means of limiting the seismic forces induced in a building by supporting the structure on devices that enable relative movement to occur between the foundation and superstructure when the force rises to a predetermined level.

Base shear Base shear is the shear force acting between the foundation soils and the building due to the inertial force induced in the structure due to the ground motion.

Bending moment See section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Bond stress The shear stress between reinforcement and concrete.

Building classification Buildings are classified in terms of importance levels 1 to 5 in AS/NZS 1170.0. Level 1 is for the lowest, and applies, for example, to isolated farm buildings. Level 2 covers most multi-storey structures, while level 3 is for buildings that may contain a large number of people such as hotels, offices and apartment buildings over 15 storeys in height. Level 4 is assigned to buildings required to cater for medical emergencies and to be operational immediately following a major earthquake and level 5 applies to special structures outside the scope of the Standard, whose failure would pose a catastrophic risk to a large area or a large number of people. It has not been provided for in NZS 1170.5.

Building code/NZBC The New Zealand Building Code, which specifies the required performance of buildings.

Capacity design A method of ensuring a building will behave in a ductile manner if subjected to a major earthquake.

Characteristic strengths There is variability in all material properties. To allow for this, material strengths are determined by tests on a large number of samples to measure the variation in properties. With the lower characteristic yield strength, 95 per cent of the samples have strengths exceeding this value. With the upper characteristic strength, five per cent of the strengths exceed the value.

Code, or code of

Practice A document that specifies how a structure is to be designed. In New Zealand many codes of practice are developed by Standards Committees established and endorsed under the methodology and auspices of Standards New Zealand and these documents are referred to as Standards. (See also “NZ Standards” below).

Concentrically braced

frame The seismic or wind forces are transmitted to the foundation by direct axial forces in the bracing members.

Cone penetrometer test

(CPT) A means of assessing the in situ properties of a soil.

Confinement Concrete is generally confined in potential plastic hinge zones. When concrete is close to its uni-axial unconfined strength it expands laterally. By enclosing the concrete with stirrups placed around longitudinal bars the stirrups are stressed when the lateral expansion occurs and they apply a confining force to the enclosed concrete. This increases both the compressive stress and the strain that can be sustained in the concrete. Confining concrete can have the advantage of enabling plastic hinges to sustain greater inelastic deformation before failure occurs, hence increasing ductility.

Damping Structural damping refers to energy dissipation in the structure by friction between components in the building, and energy dissipated by movement between the foundations, supporting soils and other energy dissipated in the structural members. In terms of seismic design methods, NZS 1170.5 does not include energy dissipated by yielding of reinforcement or steel structural members, or the crushing of concrete.

DBE Design-based earthquake used in design for ultimate limit state.

DEE Detailed engineering evaluation, a detailed examination of a building and the building structural drawings to assess the seismic performance of the structure.

Design action An action at a point in a building, such as a bending moment, a shear force, an axial load or a displacement, which has been found in an analysis. To satisfy design requirements the building must have the capacity to resist this action.

Design strength The design strength is the nominal strength multiplied by the appropriate strength reduction factor.

Detailing Arrangement of longitudinal and transverse reinforcement in a concrete member or the location of welds and stiffeners, etc., in structural steel members.

Diagonal cracking Often referred to as shear cracking (see structural actions) in concrete and masonry members.

Diaphragm A structural element that transmits in-plane forces (diaphragm forces) to and between lateral-force-resisting elements. In buildings, floors usually act as diaphragms and are occasionally called diaphragms. Diaphragm forces are the in-plane forces acting in a floor (diaphragm).

Displacement-based

design See section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Double Tees Precast prestressed units used in the construction of some floors.

Drag bars Reinforcing bars placed in a floor slab to pick up lateral forces and transfer them to a lateral force resisting element.

Ductile detailing length The length over which reinforcement in a plastic hinge may yield or concrete may crush.

Earthquake-prone

building An earthquake-prone building is defined by section 122 of the Building Act 2004 and associated regulations. In summary, an earthquake-prone building is one that, if assessed against current standards for the erection of new buildings, would be assessed as not satisfying more than 33 per cent of the minimum design actions for strength and ductility for the ultimate limit state.

Earthquake-risk

building A building is assessed as an earthquake-risk building if, when assessed against the minimum requirements in current buildings standards, it satisfies between 33 per cent and 67 per cent of the minimum design actions for strength and ductility for the ultimate limit state.

Eccentricity In the context of this Report eccentricity refers to the distance between the centre of inertial force on a building and the centre of stiffness and/or strength of the lateral force resisting elements.

Eccentrically braced

frame A structural steel frame consisting of beam and columns but with diagonal bracing in one or more bays to reduce the magnitudes of the bending moments in the beams. The short section of beam between the diagonal braces is subjected to high shear forces and in a major earthquake this zone, known as an active link, yields in a ductile manner.

Element A structural member such as a beam, column, wall or frame made up from beams and columns, that resist structural actions.

Effective section

properties Section properties, area and second moment of area used for calculating stress levels and deformation of structural elements. Effective properties in reinforced concrete are section properties based on gross section multiplied by a factor to allow for flexural cracking of concrete.

Elongation See section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Force-based design See section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Fundamental period The fundamental period is the longest period of vibration, which corresponds to the direction being considered.

Gross section

properties Section properties based on the dimensions of the concrete section but neglecting reinforcement and cracking of concrete.

Hollow-core Precast prestressed concrete units used in the construction of some floors.

In-plane and out-of-

plane forces Forces acting in the plane of a wall as distinct from out-of-plane forces, which act in a direction normal (at right angles) to the face of the wall.

IEP Initial evaluation procedure, made to establish buildings that are likely to be earthquake- prone or earthquake-risk buildings.

Kinematic effects Effects due to the motion of bodies.

Inertial force Force induced by a mass that has been subjected to acceleration, such as occurs in an earthquake owing to ground motion.

Lateral-force-

resisting element A structural member such as a wall, or group of members such as a moment resisting frame, which is designed to provide lateral force resistance.

Low-damage or

damage-avoidance

design Design to reduce the structural damage sustained in a major earthquake, for example, base isolation, PRESSS and non-tearing floor systems.

Material strain A measure of the deformation of a section in a plastic hinge.

MCE Maximum considered earthquake, generally taken as an earthquake with a return period of 2500 years for most multi-storey buildings. Multi-storey buildings designed to current New Zealand Standards are intended to have a small margin of safety against collapse in the MCE.

Moment resisting frame A structural frame consisting of beams and columns designed to provide lateral force resistance to a building.

NBS New Building Standard, which refers to the building standards in force at the time when an assessment of an existing building is made.

Nominal strength The strength calculated assuming the materials in the member have their lower characteristic strengths.

NZ Standards (NZS) Sets of rules used in the design of buildings. AS/NZS 1170 Parts 0 to 4 and NZS 1170.5, the Earthquake Actions Standard, define the required combination of strength, stiffness and ductility that a proposed building must be designed to satisfy, while the material Standards for Structural Concrete, Structural Steel or Structural Timber provide rules on how the requirements can be satisfied.

P-delta See section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Period The time (in seconds) it takes for a structure to complete an oscillation cycle. Frequency is the inverse of period, that is the number of cycles per second.

Potential plastic hinge See section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Primary crack A crack that forms in a reinforced concrete member when the stress due to bending exceeds the tensile strength of the concrete.

Probable strength A strength calculated on the basis that the material strengths have their average values.

Rapid Assessment level 1 or 2 Rapid assessment made to see if a building has sustained damage in an earthquake. A Level 1 assessment is based on an inspection of the exterior of a building; Level 2 includes both an exterior and an interior inspection.

Return factor, R A factor that varies with the return period of the design earthquake being considered.

Response spectra A plot of the peak acceleration, or peak displacement, sustained by single degree of freedom structures with period. Design response spectra are given in design Standards (NZS 1170.5) and response spectra can be calculated from the ground motion recorded in an earthquake.

Return period Refers to the average time in years between earthquakes which give a specified intensity of shaking at a specified location.

Secondary crack A crack formed in a reinforced concrete member when the tension force transmitted across a crack by reinforcement exceeds the tensile strength of the concrete surrounding the reinforcement.

Section properties Properties of members used for calculating stresses and deformations.

Serviceability

limit state (SLS) See section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Shear core A group of walls that are joined together and can resist lateral forces. Shear cores generally surround liftshafts and stairwells.

Shear force See Section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Shear wall or

structural wall A wall that is used to resist lateral forces induced by earthquake actions.

Single degree of

freedom (SDOF) A simple structural model that can only vibrate in one mode.

Sp factor Structural performance factor used to modify design response spectra.

Spectral shape factor A set of values that defines the shape of the design spectra for different types of soils.

Standard penetration

test (SPT) A means of assessing the in situ properties of soil.

Strain The change in length of a building element divided by its original length.

Strain ageing Change in properties of steel that occurs with time (weeks) after the steel has been strained beyond its elastic limit (the yield strain).

Strain hardening The increase in stress with increasing strain in reinforcement when the strain exceeds the yield strain.

Strength reduction

factor A factor that is applied to the nominal strength to give the design strength.

Stress Force divided by the area of element resisting the force. For example, stress in reinforcement is equal to the force carried by the reinforcement divided by the area of reinforcement.

Torsion Twisting of a structural member, or of a building as a whole. Generally in this report it refers to the building as a whole. Twisting results from the lateral inertial forces being displaced in plane view from the centre of lateral stiffness and strength.

Ultimate limit state ULS, see section 3: Introduction to Seismic Design of Buildings, Volume 1 of this Report.

Ultimate strain In reinforcement and structural steel members this is the strain that corresponds to maximum stress in a test where the strain is progressively increased.

Unreinforced masonry

(URM) Unreinforced masonry, including brick buildings and buildings built using stone masonry.

Web stiffener An attached element that provides out-of-plane buckling restraint to the web of the member.

Yield strain The strain at the limit of elastic response.