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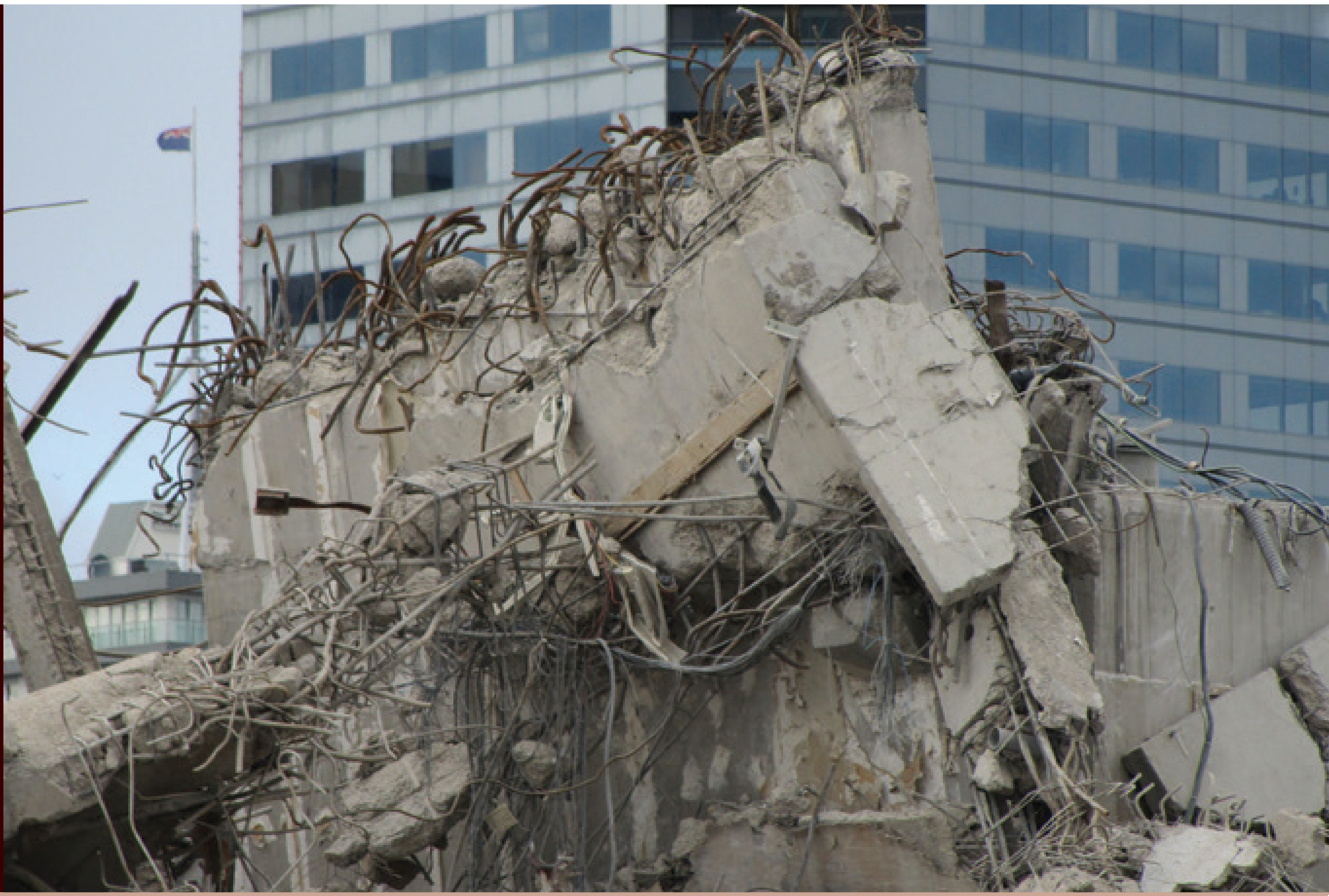

CANTERBURY EARTHQUAKES ROYAL COMMISSION: KEY RECOMMENDATIONS

September 2013

- The Canterbury earthquakes of 2010/2011 resulted in the deaths of 185 people and damage to tens of thousands of buildings.
- The Royal Commission of Inquiry that looked at building failures caused by the earthquakes produced a series of reports that included 189 recommendations.
- This bulletin is BRANZ's summary of key recommendations directly affecting engineers, architects and designers.

1.0 INTRODUCTION

1.0.1 A series of significant earthquakes struck Canterbury in 2010 and 2011. Among the largest were a magnitude 7.1 earthquake on 4 September 2010 and a magnitude 6.3 earthquake on 22 February 2011.

1.0.2 The Royal Commission of Inquiry into Building Failure Caused by the Canterbury Earthquakes was formally constituted on 11 April 2011 and completed its work in November 2012. The Commission issued an interim report and a final report, the latter in seven volumes with 189 recommendations. The reports are freely available online at www.canterbury.royalcommission.govt.nz

1.0.3 Part One (Volumes 1, 2 and 3, and recommendations 1–70) of the final report contains recommendations that informed early decision-making about recovery from the earthquakes.

1.0.4 Part Two (Volume 4, and recommendations 71–106) considers earthquake-prone buildings.

1.0.5 Part Three (Volumes 5, 6 and 7, and recommendations 107–189) includes the results of the investigation into the collapse of the Canterbury Television (CTV) building (where 115 people died) and matters relating to the systems and skills required to ensure that buildings are well designed and well built and that, following an earthquake, damage to buildings can be assessed and appropriate actions taken.

1.0.6 This bulletin is a BRANZ summary of the key findings and recommendations that have a direct impact on the work of construction industry professionals including engineers, architects and designers.

1.0.7 Many recommendations suggest further research, reviews of legislation, standards, changes to building consent authority (BCA) policies and practices, recommendations to government ministries and other actions that will eventually affect industry professionals if and when they are enacted. Those recommendations are noted only briefly in section 4.0 of this bulletin. They are available in full in the Commission's reports.

1.0.8 Some recommendations (especially 111–146) cover the specialised area of building evaluation after an earthquake. These recommendations are not covered in this bulletin but are available in full in the Commission's reports.

1.0.9 For an explanation of terms, see BRANZ Bulletin 558 *Earthquake terminology* and the glossary in Appendix 4 of the Royal Commission's Interim Report issued in October 2011 and available online.

2.0 RECOMMENDATIONS

2.0.1 The numbers that appear in brackets at the end of each quoted recommendation in this bulletin are the reference numbers from the Commission's final report.

2.1 SITE INVESTIGATION AND SOIL TESTING

2.1.1 The Royal Commission made detailed recommendations on site investigations, ground improvement and foundation design. Some apply especially to Christchurch, but many are of wider application, including these three:

- There should be greater focus on geotechnical investigations to reduce the risk of unsatisfactory foundation performance. (4)
- A thorough and detailed geotechnical investigation of each building site, leading to development of a full site model, should be recognised as a key requirement for achieving good foundation performance. (3)
- Greater use should be made of in-situ testing of soil properties by the cone penetrometer test (CPT), standard penetration test (SPT) or other appropriate methods. (7)

2.2 GROUND IMPROVEMENT

2.2.1 Ground improvement, where used, should be considered as part of the foundation system of a building and reliability factors included in the design procedures. (22)

2.2.2 Ground improvement techniques used as part of the foundation system for a multi-storey building should have a proven performance in earthquake case studies. (23)

2.3 FOUNDATION ACTIONS AND DESIGN PHILOSOPHY

2.3.1 Where liquefaction or significant softening may occur at a site for the serviceability limit state (SLS) earthquake, buildings should be founded on well-engineered deep piles or on shallow foundations after well-engineered ground improvement is carried out. (10)

2.3.2 Conservative assumptions should be made for soil parameters when assessing settlements for the SLS. (11)

2.3.3 Foundation deformations should be assessed for the ultimate limit state (ULS) load cases and overstrength actions, not just foundation strength (capacity). Deformations should not add unduly to the ductility demand of the structure or prevent the intended structural response. (12)

2.4 FOUNDATIONS

2.4.1 For shallow foundations, soil yielding should be avoided under lateral loading by applying appropriate strength-reduction factors. (16)

2.4.2 Shallow foundations should be designed to resist the maximum design base shear of the building, so as to prevent sliding. Strength-reduction factors should be used. (20)

2.4.3 For deep pile foundations, soil yielding should be permitted under lateral loading, provided that the piles have sufficient flexibility and ductility to accommodate the resulting displacements. In such cases, strength-reduction factors need not be applied. (17)

2.5 LATERAL LOADING AND FOUNDATIONS

2.5.1 Where there is a risk of significant liquefaction, deep piles should be designed to accommodate an appropriate level of lateral movement of the surface crust even when they are far from any watercourse. (27)

2.5.2 Base friction should not be included as a mechanism for lateral load transfer between the ground and the building when it is supported on deep piles. (28)

2.5.3 If reliance is to be placed on passive resistance of downstand beams and other vertical building faces, a realistic appraisal of the relative stiffness of the load-displacement response of the passive resistance compared to the pile resistance should be made. (29)

2.5.4 For buildings on deep piles, it is not essential that the calculated lateral capacity of the foundations should exceed the design base shear at the ULS, provided that the piles have sufficient flexibility and ductility to accommodate the resulting yield displacement and kinematic displacements. (30)

2.5.5 There are major problems in the use of inclined piles where significant ground lateral movements may occur. Where the use of inclined piles is considered, the kinematic effects that may generate very large axial loads that could overload the pile and damage other parts of the structure connected to the pile should be considered. (31)

2.6 BUILDING ELEMENTS THAT ARE NOT PART OF THE PRIMARY STRUCTURE

2.6.1 The principles of protecting life beyond ULS design should be applied to all elements of a building that may be a risk to life if they fail in an earthquake. (63)

2.6.2 In designing a building, the overall structure, including the ancillary structures, should be considered by a person with an understanding of how that building is likely to behave in an earthquake. (64)

2.6.3 Building elements considered to pose a life-safety issue if they fail should only be installed by a suitably qualified and experienced person, or under the supervision of such a person. (65)

2.6.4 To prevent or limit … secondary damage, engineers and architects should collaborate to minimise the potential distortion applied to non-structural elements. Particular attention must be paid to prevent the failure of non-structural elements blocking egress routes. (70)

2.7 MEANS OF EGRESS

2.7.1 Critical elements such as stairs, ramps and egress routes from buildings should be designed to sustain the peak for inter-storey drifts equal to 1.5 times the inter-storey drift in the ULS. In calculating this inter-storey drift, appropriate allowance should be made for elongation in plastic hinges or rocking joints with an appropriate allowance for construction tolerance. NZS 1170.5:2004 *Structural design actions – Part 5: Earthquake actions – New Zealand* and the relevant materials standards should be modified to provide for this requirement. (62)

2.7.2 Recommendation 70 (see 2.6.4) highlights the role that non-structural elements can play in blocking egress routes.

2.8 GENERAL RECOMMENDATIONS DIRECTED TO DESIGN ENGINEERS

2.8.1 There should be greater cooperation and dialogue between geotechnical and structural engineers. (53)

2.8.2 Designers should define load paths to ensure that the details have sufficient strength and ductility to enable them to perform as required. (54)

2.8.3 Structural engineers should assess the validity of basic assumptions made in their analyses. (55)

2.8.4 Appropriate allowance should be made for ratcheting where this action may occur. (56)

2.8.5 Structural engineers should be aware that current widely used methods of analysis do not predict elongation associated with flexural cracking and the formation of plastic hinges. (57)

2.8.6 In designing details, compatibility in deformations [should be] maintained between individual structural components. (58)

2.8.7 Structural engineers should be aware of the relevance of the tensile strength of concrete and how it can influence structural behavior. (59)

2.9 ROLES, RESPONSIBILITIES AND BUILDING CONTROLS

2.9.1 The Commission noted that quality assurance is vital in the structural design of complex buildings. It found inconsistent application requirements and consent decisions among building consent authorities (BCAs) around the country and varying levels of capability within BCAs. It noted that the experience and skill level of structural engineers also varied.

2.9.2 These variations pose risks for the quality of buildings.

2.9.3 A structural chartered professional engineer should be engaged at the same time as the architect for a complex building. (163)

2.10 LOW-DAMAGE BUILDING TECHNOLOGIES

2.10.1 Volume 3 of the final report, containing recommendations 66–70, describes how low-damage technologies can give better seismic performance, with some limitations. Practical examples built from concrete, steel and timber are presented along with the benefits, challenges and costs.

3.0 EXISTING EARTHQUAKE-PRONE BUILDINGS

3.0.1 In Volume 4 of its final report, containing recommendations 71–106, the Royal Commission looks at how to define and treat existing New Zealand buildings that are likely to perform poorly in earthquakes.

3.0.2 The report makes recommendations on the assessment of existing buildings and retrofit work required on existing buildings.

3.0.3 The Commission reviewed the characteristics of unreinforced masonry (URM) buildings, which lack the capacity to resist seismic actions when compared to more recent steel and reinforced concrete buildings. Failure of URM buildings resulted in the deaths of 39 people in the 22 February 2011 earthquake.

3.0.4 The Commission considers that, to protect life safety, there is no justification to set the shaking level to be resisted for earthquake-prone structures at greater than one third of the requirements for a new building. However, because some elements of URM buildings pose a particular source of danger, it considered that a higher level of protection should be given to them; in particular, chimneys, parapets, ornaments and external walls.

3.0.5 The recommended retrofit work to URM buildings is as follows:
- Free-standing masonry walls of unknown structural strength should be adequately restrained or demolished. (71)
- For unreinforced masonry buildings, falling hazards such as chimneys, parapets and ornaments should be made secure or removed. (77)
- The design actions for the elements and connections to be strengthened should be based on the provisions in NZS 1170.5: 2004 Section 8 – *Requirements for parts and components*. (78)
- The external walls of all unreinforced masonry buildings should be supported by retrofit, including in areas of low seismicity. (79)

3.1 ASSESSMENT OF AND RETROFIT OPTIONS FOR EARTHQUAKE-PRONE BUILDINGS

3.1.1 The Commission considered how existing buildings could be assessed for seismic resistance.

3.1.2 It recommended that the detailed assessment of URM buildings that are earthquake-prone should take into account the potential need to:
- ensure adequate connection between all structural elements of a building so that it responds as a cohesive unit
- increase the in-plane shear strength of masonry walls, or
- introduce high-level interventions (such as the insertion of steel and/or reinforced concrete frames) to supplement or take over the seismic resisting role from the original unreinforced masonry structure. (80)

3.2 SPECIFIC ASSESSMENT ISSUES AND EDUCATION NEEDS

3.2.1 The Commission recommended the following in the assessment of existing buildings for their potential seismic performance:
- Individual structural elements should be examined to see if they have capacity to resist seismic and gravity load actions in an acceptably ductile manner.
- Relatively simple methods of analysis (such as the equivalent static method and/or pushover analyses) may be used to identify load paths through the structure and the individual structural elements for first mode type actions.
- The significance of local load paths associated with higher mode actions should be considered. These actions are important for the stability of parts and portions of structures and for the connection of floors to the lateral force resisting elements.
- The load path assessment should be carried out to identify the load paths through the different structural elements and zones where strains may be concentrated or where a load path depends on non-ductile material characteristics, such as the tensile strength of concrete or a fillet weld where the weld is the weak element.
- While the initial lateral strength of a building may be acceptable, critical non-ductile weak links in load paths may result in rapid degradation in strength during an earthquake. It is essential to identify these characteristics and allow for this degradation in assessing potential seismic performance. The ability of a building to deform in a ductile mode and sustain its lateral strength is more important than its initial lateral strength, and sophisticated analyses such as inelastic time history analyses may be carried out to further assess potential seismic performance. However, in interpreting the results of such an analysis, it is essential to allow for the approximations inherent in the analytical models of members and interactions between structural members, such as elongation, that are not analytically modelled. (109)

3.2.2 Arising from the Commission's study of the CTV building, they found that it is important that the following, in particular, should be examined:
- the beam-column joint details and the connection of beams to structural walls
- the connection between floors acting as diaphragms and lateral force resisting elements, and
- the level of confinement of columns to ensure that they have adequate ductility to sustain the maximum inter-storey drifts that may be induced in a major earthquake. (110)

3.2.3 The Commission gave detailed recom-mendations on the training or guidance that should be provided so that structural engineers are aware of key issues when assessing existing buildings, including the following:
- In some reinforced concrete buildings designed under pre-1995 standards, the columns provided primarily to support gravity loading had inadequate confinement reinforcement to sustain the inter-storey drifts associated with the ULS. The recommendation explains some of the reasons behind this.

- There are structural weaknesses in existing buildings due to aspects of design not being adequately considered in earlier design standards.
- In assessing potential seismic performance, particular attention should be paid to ensuring that seismic gaps for isolating stairs or separating buildings, or parts of buildings, have been kept clear. (60)

3.3 EARTHQUAKE-PRONE BUILDING LEGISLATION

3.3.1 The Commission recommended that the legislation should be changed to provide greater enforcement of the assessment, strengthening or demolition requirements by territorial authorities within tight timeframes. (82–87)

3.4 INCLUSION OF RESIDENTIAL BUILDINGS

3.4.1 Section 122 of the Building Act 2004 excludes buildings that are used wholly or mainly for residential purposes from classification as earthquake-prone, unless they are of two or more storeys or contain three or more household units. This means the majority of dwellings are not covered by the legislation in this regard.

3.4.2 The Commission considered that there are clearly some elements of residential buildings that pose hazards in earthquakes – for example, URM chimneys – and it is desirable that these should be made more resilient. It also considered that the significance of this issue is one that will vary across New Zealand, depending on the seismic risk of the region and the nature of the housing stock. It considered that this should be addressed by territorial authorities in consultation with their communities.

3.4.3 The Commission specifically recommended that the Building Act 2004 should be amended to authorise territorial authorities to adopt and enforce policies to address hazardous elements in or on residential buildings (such as URM chimneys) within a specified completion timeframe consistent with that applied to non-URM earthquake-prone buildings in their district. (99)

3.5 PUBLIC UNDERSTANDING OF EARTHQUAKE RISK TO BUILDINGS

3.5.1 The Commission considered that it is important to improve New Zealanders' understanding of the nature of a building they may be buying, using or passing by.

3.5.2 It considered that developing a simple grading system for existing buildings – using letter grades A to E – would be easily understood by territorial authorities, building owners, tenants and the general public (Volume 4). The Commission pointed out that the general public are familiar with such grades and could more easily understand that a D or E grade would indicate a building that poses a clear earthquake risk.

3.5.3 The engineering and scientific communities should do more to communicate to the public the risk that buildings pose in earthquakes, what an assessment of building strength means, and the likelihood of an earthquake. (103)

4.0 GENERAL RECOMMENDATIONS

4.0.1 Where mesh has been used to transfer diaphragm forces that are critical for the stability of a building in a major earthquake, retrofit should be undertaken to ensure that there is adequate ductility to sustain the load path. (61) This is an issue for existing buildings and not necessarily just those that are earthquake-prone.

4.0.2 Where holes are required to be drilled in concrete, critical reinforcing should be avoided. If it cannot be avoided, specific mention should be made on the drawings and specifications of the process to be followed if steel is encountered, and inspection by the engineer at this critical stage should be required. (107)

4.0.3 Industry participants such as insurers, valuers and property managers should ensure that they are aware of earthquake risks and the requirements for earthquake-prone buildings in undertaking their roles, and in their advice to building owners. (104)

4.0.4 Many recommendations were directed towards specific organisations or groups of people, including:
Department of Building and Housing/Ministry of Business, Innovation and Employment (4, 8, 13, 18, 19, 24, 25, 65, 67–69, 72, 73, 76, 89, 102, 105, 108, 114–116, 118, 119, 123, 136, 139, 143, 145, 148, 165, 173, 177, 182, 185, 189)
Territorial authorities or building consent authorities (6, 72, 82–88, 92, 97, 99, 101, 106, 135, 139, 140, 148, 157, 162, 164, 168, 186, 187)
Professional organisations (8, 53, 54–61, 72, 103, 116, 123, 165, 173, 178, 183–185)

4.0.5 Some recommendations suggested reviews of or changes to legislation or standards:
Building Act 2004 (82–88, 90–93, 98–99, 114, 162)
Earthquake Commission Act 1993 (94)
Resource Management Act 1991 (186)
NZS 1170.5:2004 *Structural design actions, Part 5: Earthquake actions – New Zealand* (2, 32–39, 62)
NZS 3101:2006 *Concrete structures standard* (40–51)
NZS 3404:2009 *Steel structures standard* (52)

5.0 FURTHER INFORMATION

Royal Commission
The full reports of the Royal Commission along with other documents and resources are available at: www.canterbury.royalcommission.govt.nz

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