# Review of
# "The Performance of Unreinforced Masonry Buildings in the 2010/2011 Canterbury Earthquake Swarm"

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by

Fred Turner, Structural Engineer
From Sacramento, California, USA

## General Comments

The preliminary report titled "The Performance of Unreinforced Masonry Buildings in the 2010/2011 Canterbury Earthquake Swarm" effectively addresses the scope of work set forth by the Royal Commission of Inquiry into Building Failure Caused by the Canterbury Earthquake. It provides details of the characteristics and value of unreinforced masonry (URM) buildings in New Zealand, their seismic vulnerability, descriptions of their performance in the earthquakes, and information on technologies and priorities for seismic improvements. The report, which is the subject of my review below, also describes representative URM buildings and comments on the adequacy of current practices and methodologies that may be adopted in response to the disasters.

For the purposes of this review, I understand that several other reports are being prepared that address other required interim or final recommendations relating to URM buildings that are delineated in the Commission's Terms of Reference and that are not explicitly addressed in the preliminary report that is the subject of this review. Since I have not received and have limited knowledge of other reports, I am not commenting on the adequacy of this preliminary report or others as they pertain to the Commission's Terms of Reference.

The preliminary report also acknowledges its interim status by indicating that additional information on URM building damage statistics from the 22 February 2011 earthquake and cost summaries for various seismic retrofit technologies will be provided in a later version.

This review of the preliminary report has two parts. Part 1 provides general comments and recommendations for improving the report. Part 2 provides more specific suggestions and comments in a separate portable document format (pdf) file that contains notes and recommended edits.

## Part 1 – General Comments

### Comments on the Report's Recommendations in the Executive Summary and Section 7

The report's recommendations in the Executive Summary and Section 7 are a reasonable start and could be improved in the following ways:

- **Limitations of Retrofits:** The recommendations should acknowledge, as evidenced from past retrofit performance, that it is neither practical nor feasible to state conclusively that the public can be effectively protected from "all" falling hazards and that "strengthened URM buildings will survive severe earthquake ground motions." Other similar policy documents use qualifying phrases to characterize the limits of performance objectives such as: "risk reduction programmes" (NZSEE 2006);"reduce the risk of life or injury" (IEBC 2009); "decrease the probability of loss of life, but this cannot be prevented" (IEBC 2006); "compliance with this standard does not guarantee such performance" (ASCE 2006); and "reduce damage and needed repairs" (CHBC, 2010). The reason for proposing these clarifications is that the public should be made aware of the practical limitations of seismic retrofits, considering the margins of safety from collapse and parts of buildings falling, particularly in light of the large known variability and uncertainty of ground motions, as well as variations and uncertainty in the quality of building materials, the states of repair, and the integrity of connections between building components. In a retrofitted URM building, a single masonry unit that may fall from an appreciable height has the potential to be lethal or cause serious injury. Retrofits that represent best practices may not always guarantee that all masonry units will remain in place, nor that URM buildings will always avoid cost-prohibitive repairs or demolitions after experiencing severe ground motions.

- **Building Improvement Considerations and Alternatives:** Recommendation numbers 3, 4, 5 and 8 to require building improvements nationwide should be contingent upon consideration of the benefits compared to the costs of such investments to account for the time value of money, socio-economic and cultural implications, recurrence intervals of earthquakes, the time frames that will be required to reasonably accomplish the improvements, the ability of owners to finance such investments, and the capacity of the design and construction industry. Past experience suggests that owners, when given the option to conduct only Stage 1 and 2 interim retrofits, typically find that a phased approach is not cost-effective due to the high costs of disruption during construction. In the closing remarks, the statement: "the cost of implementing stage 1 and 2 improvements will not be excessive and should be within the budget capability of most building owners" needs to be substantiated with unit costs per square meter and surveys documenting the owners' ability to finance the improvements. Consider merging Stages 3 and 4 since prevailing practice recognizes that increasing flexural capacity can trigger other failure modes to occur first so both stages should be addressed concurrently. Alternatives for the minority of owners who cannot afford such improvements should also be identified. Additional risk management techniques such as such as providing incentives, removing disincentives, and encouraging or requiring replacements of buildings as well as the implications of doing nothing should also be compared with these recommendations so that the public and policymakers can make more informed decisions. Due to the size and complexity posed by collapse-risk buildings, significant progress will require decades of effort, so long-term programme management techniques that rely on metrics coupled with investments in research and development can create significant efficiencies over time.

- **Inventories of URM Buildings:** In recommendation 1, inventories of buildings should include sampling of building sizes, occupancies, and financial, social and cultural conditions that are representative of the URM building stock in each jurisdiction.

- **Two additional recommendations warrant consideration**:

  - Adequate staffing and retrofit training within building regulation enforcement agencies should be implemented to ensure that: 1) retrofit designs are thoroughly checked for compliance with regulations before construction permits are issued; 2) retrofit construction is thoroughly inspected to ensure strict compliance with approved plans and; 3) damaged buildings are effectively assessed, placarded, barricaded and stabilized after future earthquakes.

  - Funds for earthquake engineering and social science research and development should be allocated to support decision-making and ensure an effective national retrofit programme, to document earthquake performance, to install and maintain more strong motion recording instruments in and near retrofitted buildings, and to conduct engineering testing and analytical studies to help develop more reliable risk management practices.

**Comments on Section 6 Costs of Seismic Improvements**

- In Table 6.2, a source for the unit cost for the 2008 buildings greater than 33% and less than 67% that is shown as 450 $\$/m^2$ should be provided. The total cost for these 2008 buildings could be reduced to $490 M bringing the overall total to a reduced value of $1330 M. Accounting for the likely demolition of some of the non-historic URM buildings can also significantly lower overall costs. However, additional cost allowances or contingencies for fire safety and disabled access requirements and other commensurate requirements associated with retrofits should be added to the estimates.

- Cost estimates for individual stages 1, 2, 3 combined with 4 should be provided.

- Statements should be added to notify readers that the costs of repairing and retrofitting earthquake-damaged buildings may be considerably higher than retrofitting undamaged buildings.

- Provide a description of the costs of other alternatives such as demolition and replacement. For example, the cost of demolition can be significantly offset by the salvage value of used brick.

- Consider adding a section describing the unit costs and total costs to retrofit concrete frame buildings with URM infill walls or provide a reference to another report that addresses these buildings.

**Comments on Section 7 Closing Remarks**

- In remark 1, the performance of adhesive anchors in retrofitted URM buildings warrant designation as a significant lesson learned, though perhaps not a surprise per se, because many anchors failed in bond slip, particularly those with short embedment lengths and in walls with low mortar strengths.

- Remark 2 should be modified to acknowledge that retrofit and alteration practices for URM buildings have evolved considerably over the past several decades. In most cases, early retrofits should be reevaluated and in some cases re-evaluations will likely identify the need for additional retrofitting. Damaged, previously-retrofitted URM buildings may also warrant additional retrofitting in conjunction with repairs. Since requirements for new buildings have recently been increased in Canterbury, this increase will have significant implications for retrofitted buildings, including those recently completed.

**Comments on Section 1 Introduction and Background**

- A characterization of the eras or decades in which most of the existing retrofits were designed in New Zealand should also be added since practices have changed over time. This information will help distinguish how many retrofits were recently completed compared to older retrofits that may warrant re-evaluations and additional retrofits.

- Section 1.3.1 should include a discussion of New Zealand's policies and practices for bracing URM parapets. Estimates of the rate of compliance with parapet policies and judgments about their effectiveness should be included.

- In Section 1.3 consider adding a non-technical discussion about recent trends in earthquake engineering that are moving away from force-based approaches such as the percentage of new building standards (%NBS) and toward performance-based earthquake engineering, also called displacement-based engineering. Some of these newer techniques may yield more reliable and potentially lower retrofit costs than force-based methods, albeit with somewhat higher design costs that typically rely on more realistic, nonlinear analyses techniques.

- Section 1.4 should include a brief summary of ground motions in Lincoln and Lyttleton for the September and February earthquakes. In Lincoln, ground motions were substantially higher than in the Christchurch CBD in the Darfield earthquake. And Lincoln provided several examples of the performance of retrofitted and unretrofitted URM buildings in more severe, longer-duration ground motions than in the CBD. In Lyttleton, ground motions and soil conditions are considerably different than Christchurch CBD. While this is somewhat beyond the scope of work, including comparative discussions about Lincoln and Lyttleton will emphasize that the public should grasp that performance will vary considerably based on locations, soil and rock conditions, differences in ground motions, as well as building earthquake resistance.

- In Section 1.4, consider adding further descriptions and a map showing the locations of and distances between the few recordings in Christchurch CBD. The recordings demonstrated significant variations in the intensities, maximum directions, and period content of ground motions over relatively short distances. This is not unique to the Canterbury sequence of earthquakes. Similar large variations in recorded ground motions across short distances have also been recorded in other past earthquakes such as Parkfield (SMC 2004). Large variabilities in ground motions can render generalizations about the performance of buildings problematic. Had more instruments been installed to record the motions of the ground, as well as motions of the floors and roofs of buildings and other structures, New Zealand would have obtained a much more comprehensive understanding of the demands experienced by the built environment.

- Adding a summary of what other countries have done to reduce the risk of collapse in URM buildings will help substantiate the proposed recommendations (CSSC, 2006) (MLIT 1995).

**Comments on Section 2.5 Seismic Vulnerability of the New Zealand URM Building Stock**

- Consider adding a paragraph discussing the fact that performance of URM buildings in one earthquake is not necessarily indicative of future performance in other earthquakes. Furthermore, earthquakes are typically not efficient in causing uniform damage to all URM buildings in a region. Damage will often vary widely over short distances for a variety of reasons including soil and rock conditions, wave propagation effects, building orientation, quality and integrity of building materials, their connections, and serendipity. So owners of undamaged or slightly damaged URM buildings may misconstrue their sense of security since similar performance in future earthquakes is not necessarily assured by past performance. Even slightly damaged URM buildings are considerably more vulnerable in future earthquakes and aftershocks since their strength and stiffness tend to degrade with each additional cycle of significant motion. Therefore, owners of slightly damaged or undamaged URM buildings will likely still need to evaluate, repair and retrofit their buildings to ensure reliable performance in future earthquakes.

- Others have documented the challenges of managing damaged unreinforced masonry buildings (Standing Rubble, 1988). There may be value in discussing these issues in this report and researching these efforts to adapt lessons from those experiences for use in New Zealand.

- Consider adding a section describing in non-technical terms how URM buildings respond to earthquakes, how failures, falling hazards, and partial collapses tend to propagate from the tops of the buildings down and fall outward around the perimeters. The greatest risk to life exists immediately outside of URM buildings, so occupants should be advised to drop, cover, and hold on under sturdy furniture during ground shaking. Panicking and running out of URM buildings will typically expose occupants to far more risk from falling masonry than staying inside.

- Add a section describing concrete frame and steel frame buildings with URM infill walls. Estimate the number of such buildings in New Zealand and their retrofit costs, where warranted.

**Comments on Section 3 Observed Performance**

- Brief descriptions of the performance of retrofitted and unretrofitted URM buildings in Lincoln and Lyttleton should be included, particularly since their performance can help elucidate how each earthquake and aftershock can produce a wide range of effects.

- In Section 3.1.3 Chimneys (similarly in Section 4.1), consider noting that some chimney bracing can have limited effectiveness particularly if braces are connected to flexible wood roofs since their movements can be much larger and incompatible compared to the movements of stiffer chimneys (ATC 50-1, 2002)

- Consider adding a section describing how unsecured gabled walls and parapets fell onto and penetrated through lower adjacent roofs causing partial collapses, potentially posing serious life-threatening conditions to occupants of the lower buildings. This risk can be addressed by considering higher retrofit priorities for taller, bigger buildings.

- In Section 3.1.5, consider adding a discussion of the performance of parapets that sustained hairline cracks in the Darfield earthquake or subsequent aftershocks such as the Boxing Day event, only to collapse in the February 22 aftershock. Perhaps after future earthquakes, more precautionary measures should be taken with URM buildings. Those with minor damage may warrant barricading to keep the public from being exposed to falling hazards in aftershocks, more rigorous assessments for loss of integrity, temporary stabilizations and repairs.

- Consider adding subsections describing post-earthquake safety assessment practices, barricading, temporary stabilization and repair efforts as well as their effectiveness in the February 22 and June 13th aftershocks.

- Describe approximately how many URM buildings were retrofitted or partially retrofitted prior to September 2010 and how their range of performance compared with the range of performance of unretrofitted URM buildings nearby.

- Add a section on the performance of concrete frame buildings with URM infill walls or a reference to a separate report by others on this subject.

**Comments on Section 4 Techniques for Seismic Improvement**

- This section appears to be derived from another document that was written primarily for an audience of preservation architects. As drafted, it implies that all URM buildings have historical significance and character-defining features. As a result, the section focuses on concepts of reversibility and architectural compatibility. The absence of commensurate discussions about the safety and reliability of various retrofit techniques gives readers the impression that reversibility and compatibility may be higher priorities than occupant safety and repairability. For non-historic buildings, preservation-related considerations may not necessarily be priorities. Language that describes and evaluates the relative safety, margins against collapse and reliability for the various retrofit techniques should be included.

Priorities and tradeoffs relating to the design of retrofits in non-historic URMs should be added.

**Comments on Section 5 Representative Buildings**

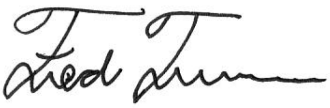
- For each of the retrofitted buildings, consider adding a description of the safety assessment placarding and the percent of New Building Standards (%NBS) criteria for their retrofit designs, and other relevant project-specific seismic performance criteria that describes the intent of the original retrofits. Consider comparing the actual performance of retrofitted buildings with their design criteria.

**Part 2 – Specific Comments and Minor Suggestions for Editing –** See the attached pdf file with my notes titled:
ENG ACA 0001F+FT Report to the Royal Commission of Inquiry final V2 Aug 181.pdf

In closing, I find that Professors Jason Ingham and Michael Griffith have produced a remarkably good report. They are making excellent progress toward meeting the Royal Commission's scope of work.

Thank for giving me the opportunity to review their work and offer advice to you. I wish all of you the best of success in your efforts.

Respectfully submitted,



Fred Turner, SECB

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