

## **Natural Hazards Research Platform**

### **Contest 2012 – Final Report**

**Title: Preservation of heritage unreinforced masonry buildings through more appropriate retrofit solutions**

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**Key message for media: Why are these findings important?**

Industry-accepted solutions for the securing of URM parapets and the securing of flexible timber diaphragms to unreinforced masonry (URM) walls were experimentally validated to allow structural engineers to be familiar with these best-practice designs, contractors to be conversant with the required implementation, and owners of URM buildings to be proactive in seeking advice on best-practice earthquake strengthening techniques for their buildings. Identification and material characterisation of the stone masonry building stock of New Zealand was also conducted. A total of approximately 600 stone masonry buildings were identified.

**Abstract:**

Following the 2010/2011 Canterbury Earthquake sequence and in response to the recommendations of the Canterbury Earthquakes Royal Commission, a research study was undertaken to experimentally validate best practice structural details for securing unreinforced masonry (URM) walls to flexible timber diaphragms and securing of URM parapets of vintage URM buildings in moderate and high seismic zones to alleviate the potential for out-of-plane wall failures. A parallel research study was undertaken on characterisation of the failure modes observed in stone masonry buildings during the 2010/2011 Canterbury Earthquake sequence and a detailed inventory of all stone masonry building throughout New Zealand was completed with a total of approximately 600 stone masonry buildings being identified.

**Keywords:**

Unreinforced clay brick masonry, securing URM walls, securing URM parapets, unreinforced stone masonry

## **Introduction / Background:**

In the Interim Report released by the Canterbury Earthquakes Royal Commission, it was recommended that: “6. throughout New Zealand, URM buildings should be improved by bracing parapets, installing roof ties and securing external falling hazards in the vicinity of public spaces; and 8. these recommendations should be implemented as soon as practicable.”

The project reported herein was funded in the Platform’s recent contestable round to address these recommendations. There are approximately 3,800 unreinforced masonry (URM) buildings remaining in NZ that contribute to a sense of identity for many communities. The goal was to develop seismic retrofit solutions to significantly reduce the risk to life and preserve New Zealand’s heritage streetscapes.

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## **Objectives or Research Aims**

### **Objective No. 1**

**Objective Title: Securing solutions for URM parapets**

**Objective Achieved?**

**Yes**

It is widely recognised that shaking table testing is the most appropriate method for reproducing the dynamic effects of earthquakes on building components. A special-purpose shake table to conduct dynamic tests on as-built and secured parapets was developed and constructed. Unreinforced masonry parapets were constructed based on commonly occurring geometries using bricks that were recycled from historic URM buildings and a mortar mix simulating historic construction. An overview of the test set-up is shown in Figure 1.



**Figure 1. Test set-up for testing securing methods for URM parapets**

Two as-built parapets and three industry-accepted retrofit solutions for the securing of URM parapets were tested. Data collected from the accelerometers and other measuring devices is currently being processed. Photogrammetry data is also being processed currently. Additional URM parapets are being constructed in order to gain a better understanding of how ultra-weak mortar mix affects the seismic performance of secured parapets.

#### **List of outputs**

- Developed and constructed a shake table mechanism to conduct dynamic tests on restrained parapets;
- 4<sup>th</sup> year Bachelor of Engineering student project report;
- Manuscript for an international technical journal is under preparation
- Appointed to NZSEE committee to write update guidance on seismic assessment of URM buildings

#### **List of end-users**

- Engineering consultancies
- New Zealand Historic Places Trust
- Ministry of Culture and Heritage
- New Zealand Society of Earthquake Engineering
- Structural Engineering Society of New Zealand

## Objective No. 2

### Objective Title: Securing solutions for diaphragms connections

#### Objective Achieved?

Yes

An in-field test program to evaluate the performance of adhesive anchor connections between unreinforced clay brick URM walls and timber roof or floor diaphragm was carried out. The study consisted of approximately 400 anchor tests conducted in eleven existing URM buildings located in Christchurch, Whanganui and Auckland.

Failure modes of adhesive anchors in existing URM walls and the influence of key variables on anchor load-displacement response, such as strength of the masonry materials (brick and mortar), anchor rod diameter size, and quality of installation were identified. In addition, the comparative performance of bent anchors and anchors positioned horizontally has been investigated.

Findings showed that anchors positioned horizontally provided superior performance (both in pull-out strength and stiffness) in comparison to bent anchors, and an optimal rod diameter of 16 mm was established. Moreover, installing adhesive anchors as per the manufacturer's instructions was critical to achieving adequate performance. This study is currently ongoing, investigating the effects of vertical accelerations and dynamic loading on the pull out capacity of adhesive anchors.

#### List of outputs

- 2013. **DIZHUR, D.**, CAMPBELL, J., SCHULTZ, A., **INGHAM, J.** Observations from the 2010/2011 Canterbury Earthquakes and Subsequent Experimental Pull-Out Test Program of Wall-to-Diaphragm Adhesive Connections, *SESOC Journal*, 27 (1);
- 2013. **DIZHUR, D.**, CAMPBELL, J., SCHULTZ, A., **INGHAM, J. M.** Experimental Pull-Out Test Program of Wall-to-Diaphragm Adhesive Connections and Observations from 2010/2011 Canterbury Earthquakes, New Zealand Society of Earthquake Engineering Conference, April 26-28, Wellington, New Zealand;
- A nationwide seminar at 6 venues to 430 professional engineers on seismic assessment and improvement of URM buildings was presented using the acquired test results;
- Appointed to NZSEE committee to write update guidance on seismic assessment of URM buildings

- Commissioned website <http://masonryretrofit.org.nz/> in order to provide a digital library of UOA retrofit research work and make it accessible by practicing engineers.

**List of end-users**

- Engineering consultancies
- New Zealand Historic Places Trust
- Ministry of Culture and Heritage
- Structural Engineering Society of New Zealand
- New Zealand Society of Earthquake Engineering

### Objective No. 3

#### Objective Title: Retrofit solutions for stone masonry buildings

#### Objective Achieved?

Yes

Characterisation of the failure modes observed in stone masonry buildings in the Canterbury earthquakes was conducted and an article to an international technical journal on these failure modes was accepted for publication.

A detailed inventory of all stone masonry building throughout New Zealand was undertaken and completed, with a total of over 600 stone masonry buildings being identified and characterised, and detailed building information being recorded. This database has been shared with the NZ Historic Places Trust. Student thesis chapter and a manuscript for a New Zealand technical journal are under preparation.

Stone and mortar sample extraction was undertaken and detailed examination of material properties on at least 10 stone masonry buildings located in Christchurch and Auckland was performed. Over 150 mortar samples were prepared and tested from stone masonry buildings and over 60 stone samples were prepared were tested. XRD analysis of mortars and microscopic analysis of stones was undertaken with the data being analysed. Student thesis chapter and a manuscript for a international technical journal are under preparation.

#### List of outputs

- 2013. LEITE, J., **INGHAM, J. M.**, LOURENCO, P. B. 'Statistical assessment of damage to churches affected by the 2010-2011 by the Canterbury (New Zealand) earthquake sequence, Journal of Earthquake Engineering, 17, 1, 73-97, <http://dx.doi.org/10.1080/13632469.2012.713562>
- 2013. SENALDI, I., MAGENES, G., **INGHAM, J.** 'Damage assessment of unreinforced stone masonry buildings after the 2010-2011 Canterbury Earthquakes'. Accepted for publication.
- Summary report and database submitted to NZ Historic Places Trust
- Test data and summary report sent to engineering consultancies conducting seismic strengthening of the tested buildings
- Established close working relationship with Francesca da Porto from University of Padua, Italy with a visiting scholar Marta Giaretton undertaking work on NZ stone masonry.
- Manuscript for a New Zealand technical journal on inventory of all stone masonry building throughout New Zealand is under preparation

- Manuscript for an international technical journal on test data acquired from stone masonry building throughout New Zealand is under preparation

**List of end-users**

- Engineering consultancies
- New Zealand Historic Places Trust
- Ministry of Culture and Heritage
- Structural Engineering Society of New Zealand
- New Zealand Society of Earthquake Engineering

## **Budget:**

### **Budget Item Average Yearly Figure**

Personnel \$92,082.00

General Operating Expenses (Include capital purchases up to \$5,000) \$81,129.50

Building Depreciation / Rental \$0.00

Equipment Depreciation / Rental \$25,000.00

Overheads \$101,788.50

Sub-contracting \$0.00

Extraordinary Expenditure \* \$0.00

Your total budget for year 1 (GST exclusive) **\$300,000.00**

Average annual budget (GST exclusive) **\$300,000.00**

## **Conclusions & Recommendations:**

- Findings from the parapet and diaphragm securing testing have been implemented into the 2012 rewrite of the NZSEE 'Red Book'. Further testing is scheduled to extend the work completed within the grant time-frame, to develop a more extensive data set.
- Results have been disseminated to the professional engineering community via a nationwide seminar series and a set of publications, with all information available for free access from the website at [www.masonryretrofit.org.nz](http://www.masonryretrofit.org.nz)
- In collaboration with the New Zealand Historic Places trust a comprehensive database of stone masonry buildings throughout New Zealand has been compiled. This database will assist with the recent recommendation by MBIE that a publically-accessible register of earthquake prone buildings be developed.

## **Acknowledgements:**

The research team acknowledge the support and securing products provided by Reids Construction Ltd, Sika (NZ) Ltd and Hilti (NZ) Ltd. Part of the URM wall-to-diaphragm connection research study was conducted with financial support from the New Zealand Natural Hazards Research Platform and RAPID grant CMMI-1138614 from the US National Science Foundation. Assistance from New Zealand Historic Places Trust, and in particular from Win Clark, is acknowledged. Support and guidance from the NZSEE committee undertaking rewriting of the 'Red Book' is also acknowledged.



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2013. **DIZHUR, D.**, CAMPBELL, J., SCHULTZ, A., AND **INGHAM, J.** Observations from the 2010/2011 Canterbury Earthquakes and Subsequent Experimental Pull-Out Test Program of Wall-to-Diaphragm Adhesive Connections, *SESOC Journal*, 26 (1), 11-20.

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2013. JAFARZADEH, R., WILKINSON, S., GONZÁLEZ, V., **INGHAM, J. M.**, GHODRATI AMIRI, G. 'Predicting Seismic Retrofit Construction Cost for Buildings with Framed Structures Using Multi-Linear Regression Analysis', *ASCE Journal of Construction and Engineering Management*, [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000750](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000750)
2013. **DIZHUR, D.**, M. C. GRIFFITH, AND J. M. INGHAM. 'In-Plane Shear Improvement of Unreinforced Masonry Wall Panels using NSM CFRP Strips' *ASCE Journal of Composites for Construction*, [http://ascelibrary.org/doi/abs/10.1061/\(ASCE\)CC.1943-5614.0000400](http://ascelibrary.org/doi/abs/10.1061/(ASCE)CC.1943-5614.0000400)
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Journal articles in press but not yet available online:

- 2013 SENALDI, I., MAGENES, G., **INGHAM, J.** 'Damage assessment of unreinforced stone masonry buildings after the 2010-2011 Canterbury Earthquakes'. Accepted for publication.
- 2013 DERAKHSHAN, H., **DIZHUR, D.**, GRIFFITH, M. C., **INGHAM, J. M.** 'In-situ out-of-plane testing of as-built and retrofitted unreinforced masonry walls', *ASCE Journal of Structural Engineering* (accepted for publication).
- 2013 MOON, L., **DIZHUR, D.**, SENALDI, I., DERAKHSHAN, H., GRIFFITH, M., MAGENES, G., and **INGHAM, J. M.** 'The demise of the URM building stock in Christchurch

- during the 2010/2011 Canterbury earthquake sequence’. *Earthquake Spectra*.
- 2013 GIONGO, I., **DIZHUR, D.**, TOMASI, R., AND **INGHAM, J. M.** ‘Field testing of flexible timber diaphragms in an existing vintage URM building’. *ASCE journal*, submitted May 2013.
- 2013 BAILEY, S., **DIZHUR, D.**, TROWSDALE, J, GRIFFITH, M. ‘Performance of posttensioned seismic retrofit of two stone masonry buildings during the Canterbury earthquakes’, *ASCE Journal of Performance of Constructed Facilities*, reviewed version resubmitted July 2013.
- 2013 **DIZHUR, D.**, GRIFFITH, M. C., **INGHAM, J. M.** ‘Out-of-Plane Strengthening of Unreinforced Masonry Walls Using Near Surface Mounted Fibre Reinforced Polymer Strips’. *Engineering Structures*, reviewed version resubmitted September 2013.
- 2013 **DIZHUR, D.**, GRIFFITH, M. C., **INGHAM, J. M.** ‘Pull-out Strength of NSM CFRP Strips Bonded to Vintage Clay Brick Masonry’. *Engineering Structures*, reviewed version resubmitted February 2013.

Published conference proceedings:

2012. **DIZHUR, D.**, **INGHAM, J. M.** ‘Report on the ‘Project Masonry’ recovery project’, SESOC NZ Conference, Auckland, 2-3 November.
2012. **INGHAM, J. M.**, LOURENCO, B. P., LEITE, J., CASTELINO, S. ‘Using Simplified Indices to Forecast the Seismic Vulnerability of New Zealand Unreinforced Masonry Churches’, Australian Earthquake Engineering Society Conference, 7-9 December, Gold Coast, Australia.
2013. GIONGO, I., **DIZHUR, D.**, TOMASI, R., AND **INGHAM, J. M.** ‘In-Plane assessment of existing timber diaphragms in URM buildings via quasistatic and dynamic in situ tests’, 2<sup>nd</sup> International Conference on Structural Health Assessment of Timber Structures, September 4-6, Trento, Italy.
2013. **DIZHUR, D.**, CAMPBELL, J., SCHULTZ, A., **INGHAM, J. M.** ‘Experimental pull-out test program of wall-to-diaphragm adhesive connections and observations from 2010/2011 Canterbury Earthquakes’, New Zealand Society of Earthquake Engineering Conference, April 26-28, Wellington, New Zealand.

**Appendices:** Copies of all manuscripts available on request.