Aaron Wilson - Research Proposal

1. Short Title of Research Proposal

In-field seismic assessment and retrofit of unreinforced masonry buildings

2. Summary of Research Proposal

New Zealand's unreinforced masonry buildings, many of which represent the predominant architectural heritage of our nation, have been proven to perform unsatisfactorily during earthquakes. To date researchers and designers have assessed expected building response and formulated seismic retrofit solutions based on limited laboratory data, and inadequately validated modelling techniques. A problem exists that throughout the world almost no in-field testing has been undertaken to generate data with which to validate the accuracy of models and laboratory driven studies of retrofit solutions.

This research proposal forms an integral part of the Seismic Retrofit Solutions research collaboration that seeks to address the comparative absence of a national platform of knowledge and expertise associated with seismic retrofit or rehabilitation of New Zealand's multi-storey buildings. This study is specifically tasked with correlating laboratory studies on seismic assessment and seismic retrofit of unreinforced masonry buildings against in-field verification of actual unreinforced masonry building response.

To address this task, in-field testing of unreinforced masonry structures will be undertaken using the University of Auckland's Mobile Field Laboratory, a facility that involves the use of sophisticated shakers to generate inelelastic responses of existing structures. It is desired to accurately determine the strength and stiffness of a full scale in-situ building up to the onset of failure, and also the limiting strength characteristics and mechanisms of failure. These results will be correlated with laboratory based studies with the ultimate goal of developing cost-effective retrofit solutions that will mitigate the effects of earthquakes on New Zealand's heritage buildings.

Section Two: Student and Qualification Details

1. Personal Details

Date of Birth:	7 January 1985
Gender:	Male
Ethnicity:	
	New Zealand European/Pakeha
NZ Citizen:	Yes *If yes, attach a certified copy of birth certificate or passport to Part B of the application*
Permanent Resident:	Yes *If yes, attach a certified copy of residency certificate to Part B of the application*

2. Proposed Course of Study

Name of Doctoral Course:	Doctor of Philosophy
Prerequisite Qualification:	Bachelor's degree with First Class or Second Class (Division I) Honours at The University of Auckland
Minimum Qualification Time	3 years
Start Date:	March 2007
If already started, % completed:	N/A
Completion Date:	February 2010
Area of Study *(Use Annex 1 in Notes):*	G4
Research Component (%):	100%
Study Component (%):	0%

Section Three: Research Proposal

1. Purpose/Proposed Outcomes

Unreinforced masonry (URM) buildings can generally be described as those that are constructed from individual units of brick or stone, bound together with a layer of mortar without the use of steel reinforcement. This construction practise became popular in New Zealand during the late 19th and early 20th century because the required construction materials were readily available and the construction methods were comparatively simple. The popularity of URM continued to grow until the 1930's, when the total destruction of almost all URM buildings during the 1931 Napier earthquake graphically illustrated that unreinforced masonry construction provided insufficient strength to resist lateral earthquake forces due to its brittle nature and inability to dissipate energy. URM construction subsequently declined in popularity following the 1931 earthquake, and national design and construction standards were introduced in 1965 that formally precluded its further use for new construction.

Unreinforced masonry buildings today represent the predominant architectural heritage in New Zealand. Whilst many URM buildings have little heritage value and are demolished to accommodate new construction on existing sites, many URM buildings are important to our heritage and must be retained for cultural as well as commercial reasons. Recognising that URM buildings perform poorly when subjected to lateral forces, it becomes evident that when the next earthquake strikes, New Zealand is at risk of:

- Incurring many deaths and injuries to those working in and around poorly performing URM buildings
- Losing many of its heritage buildings
- Suffering millions of dollars in damage and reconstruction costs

These potentially devastating outcomes have necessitated focussed structural engineering research to improve our understanding of URM building response to earthquakes and to develop retrofit solutions that mitigate these adversities. In response to this need, a collaborative research programme named Seismic Retrofit Solutions has been initiated, headed by the principal supervisor to this research proposal Dr Jason Ingham. This research collaboration provides solutions addressing the comparative absence of a national platform of knowledge and expertise associated with seismic retrofit or rehabilitation of the nation's multi-storey buildings. The University of Auckland is responsible for the component of the research agenda that considers URM buildings, addressing the following topics:

- Improved seismic assessment (Laboratory based study)
- Seismic solutions using mullions and post-tensioning (Laboratory based study)
- Seismic solutions using fibre reinforced polymers (Laboratory based study)
- Seismic solutions for diaphragm-to-wall connections and for perforated walls (Laboratory based study)
- Field testing of actual buildings
- Development of predictive techniques including damage indices
- Life cycle costing of retrofit solutions implementation.

Presently researchers and designers assess expected building response and formulate seismic retrofit solutions based on limited laboratory data, poorly validated modelling techniques, and professional engineering judgement. Very limited data is available on the seismic response of actual URM buildings, but the available data has indicated that the current state-of-the-art is often inconsistent with data obtained from in-field studies. This research proposal is an integral component within the scope of the wider Seismic Retrofit Solutions programme, with the specific task of correlating the laboratory studies on seismic assessment and seismic retrofit of URM buildings against in-field verification of actual URM building response. This endorsement of the laboratory studies will provide confidence that the developed retrofit solutions can be instituted within New Zealand's heritage URM building stock. By improving the knowledge and expertise of designers in New Zealand, the Seismic Retrofit Solutions research collaboration will produce efficient, cost-effective retrofit solutions for improving the seismic performance of URM buildings, and in turn, potentially save New Zealand lives and money.

This doctoral study will address a key issue by generation data on the actual seismic performance of real URM buildings both before and after seismic retrofits have been instituted.

2. Specific Objectives/Aims of the Research

This research proposal aims to address the absence of data on the actual performance of URM buildings in New Zealand. It is aimed at verifying laboratory studies on URM building components by correlating these findings with data acquired from in-field testing.

The primary objective of this study is to undertake a full scale test of a URM building using the University of Auckland's Mobile Field Laboratory. It is desired to determine accurately the strength and stiffness of an in-situ building up to the onset of failure, and also the post-failure strength characteristics and mechanisms of failure. This will enable the development of retrofit solutions that will not only limit the damage to the building, but also ensure that the mode of failure will be progressive and controlled; rather than instantaneous and catastrophic.

In addition to the primary objective, this study aims to achieve the following key objectives:

- Improve understanding of URM building materials
- Acquire improved data on the typical condition of New Zealand's heritage URM buildings
- Acquire improved data on component response with the intention of facilitating improved modelling of these components
- Determine strength and stiffness characteristics of building subassemblies, such as L and T shaped joint zones
- Validation of seismic retrofit solutions such as fibre reinforced plastic, mullions and post-tensioning, by correlating in-field data to laboratory studies

3. Milestones and Expected Timelines

Task	Date
Preliminary literature review	March 07-Oct 07
Initial testing of URM building materials	July 07-August 07
Initial computational modelling	August 07-Oct 07
Commence dialogue with demolition companies and building owners.	July 07 -
Locate in-field URM building components to be tested	August 07–August 08
Computational modelling of building components	January 08-February 08
Testing of candidate URM building component materials	February 08-March 08
Commence in-field testing of URM building components	March 08-May 08
Correlation of in-field data to laboratory studies	May 08-June 08
Locate appropriate URM buildings for testing	January 08-January 09
Site selection and implementation planning	Jul 08-Mar 09
Computational modelling of candidate buildings	January 09-February 09
Testing of candidate URM building materials	February 09-March 09
Commence in-field testing of full scale URM buildings	March 09-April 09

Correlation of in-field data to laboratory studies	June 09-July 09
Development and refinement of design philosophy	July 09-August 09
Publishing of finding in peer reviewed international journal	August 09-Sept 09
Dialogue with designers with a view to implementation	July 09- February 2010
Thesis authoring	Sept 09-February 2010

4. Research Methodology

Ward Demolition and Nikau Demolition are two large demolition companies resident in Auckland with whom the research team has commenced dialogue related to site access to URM buildings that have been scheduled for demolition. In 2006 this enabled a pilot final year undergraduate research project to be conducted, where the research student Hamish Grey had access to two Auckland URM demolition sites. The current project will involve further and more detailed engagement with these two demolition companies in order to establish the location and timing for URM buildings that are scheduled for demolition, and which will be suitable for full scale site testing. The appropriate buildings will be selected and subsequently the building owners will be approached in order to obtain necessary permission to gain site access. Initially only material data and small scale testing on individual building components is proposed, in order to progressively develop a growing understanding of building response, to facilitate a growing partnership with the demolition companies, and to ensure that safe work site practices are adhered to. Each site will be extensively reviewed to determine the exact procedure in which the building is going to be tested. Possible aspects to consider will be:

- Possible radius of destruction debris
- Neighbouring buildings
- Civilians within the vicinity of the test
- Site accessibility

The technical study will begin by acquiring materials from URM buildings built between approximately 1900 and 1930, such as the masonry blocks and mortar. These materials will be tested in the Civil Materials laboratory to determine specific structural characteristics with the intention of fully understanding the behaviour of the individual units before testing building components.

The Seismic Retrofit Research Board is an industry advisory panel to the Seismic Retrofit Solutions research programme and has been convened under the auspices of the Structural Engineering Society of New Zealand (SESOC) to provide professional input and independent review of the proposed research agenda in order to ensure that research findings are of value to practising New Zealand structural designers. Members of the SRRB will be contacted in order to identify specific URM construction detailing for which they wish to obtain improved data.

In order to determine the magnitude of the actions required to simulate lateral earthquake forces, computational models of buildings and components will be developed using a suitable structural modelling programme. Various building sizes and component shapes will be explored so that the forces determined from the model can be used to predict the number of shakers required to simulate lateral earthquake loads. This will include the modelling of a full-scale multi-storey building and such building components as walls, and L and T shaped joint zones.

In-field testing of building components, such as free standing URM walls will commence using the Mobile Field Laboratory. By beginning testing on a small scale, the performance of the mass shakers can be established with the ultimate goal of verifying the potential of inducing simulated earthquake forces into a full scale building. The small scale tests will also provide valuable information about the behaviour and characteristics of unreinforced masonry building components such as the L and T shaped joint zones.

The process by which the testing will be monitored will be to densely instrument the building components with an array of data acquisition instruments that record deformations, forces, rotations, and strains. In addition, the testing will be paused periodically so that observations can be made regarding progressive damage. Results will be reported using standard graph formatting to interpret performance and the implication for design.

Additional funding and development of the Mobile Field Laboratory will be conducted concordantly with this study, increasing the ability to undertake in-field testing of structures of increasing magnitude. It is envisaged that upon the completion of the MFL, the necessary dialogue, permits and planning will have been completed in order to undertake a full-scale test of a multi-storey URM building. Monitoring of a full-scale test will be similar in nature to that of building components, but on a larger scale with instruments being attached to key locations such as the column bases, beam centres and joint zones.

All experimental data recorded from the field tests will be relayed to the Data Visualisation Laboratory (DVL) at the University of Auckland where it will be uploaded and archived with the United States Network for Earthquake Engineering Simulation (NEES). This will provide a unique contribution to the network with the potential of forming international research collaborations. Communication has already begun with several international institutions involved in similar research regarding possible collaborations with this project including, Iowa State University, University of California at San Diego, University of Notre Dame in Indiana and the National Centre for Research in Earthquake Engineering (NCREE) in Taiwan.

Data recorded from in-field testing, conveying time-history response characteristics of building structures and components, will be correlated with the laboratory studies on seismic retrofit systems for URM buildings with the specific intention of verifying these designs with actual building response mechanisms.

Throughout this study, results will be disseminated to New Zealand practitioners and to international researchers through attendance and participation at conferences for earthquake engineering and masonry. Results will also be disseminated to the SRRB through specifically scheduled meetings with the intention of receiving feedback from a practitioner viewpoint to maintain the practical value of the research findings. Results will also be published in leading peer-reviewed international journals.

5. Knowledge Transfer

The findings of this study will be presented at national and international conferences on earthquake engineering and masonry construction and materials. Dissemination of research findings will also be achieved by publishing articles in international journals that are peer-reviewed by leading research fellows from around the world.

The conclusions and recommendations that are established from this study will be encapsulated in the Seismic Retrofit Research Manual that will accompany the New Zealand Society for Earthquake Engineering (NZSEE) document 'Assessment and Improvement of the Structural Performance of Buildings in Earthquake' (March 2003). This document contains guidelines for evaluating and strengthening reinforced concrete and structural steel buildings designed prior to the advent of modern codes (NZS 4203:1976 and subsequent versions).

6. Intellectual Property Plan/Agreement (where appropriate)

N/A

7. Ethical and/or Regulatory Approvals (where appropriate)

It is envisaged that no ethical approval will be required for this research proposal. The necessary authorisation and instruction in site safety will be completed before the in-field testing stage of this research proposal is undertaken.

Section Four: Benefit to New Zealand

As outlined in the foregoing section, unreinforced masonry buildings make up a significant portion of our nation's heritage and historical landmarks but are known to perform poorly during earthquakes. With no current effective remedial solutions, New Zealand is at risk of losing much of its visual history during the next earthquake event.

This research proposal has the potential to be a forerunner in assisting the development of cost-effective retrofit solutions for unreinforced masonry buildings. More specifically, the response of URM buildings to lateral earthquake forces will be better understood using the data acquired from full scale testing of URM buildings and in turn will aid the design and implementation of practical retrofit systems. It is envisaged that these systems will significantly improve the ability of URM buildings to dissipate energy induced by earthquakes and hence withstand these events with as little residual damage as possible.

This study also has the potential to be of significant economic benefit to New Zealand. Remedial work to heritage buildings will inevitably need to be undertaken, but without focussed research, these solutions will not be 'cutting edge' and hence will require conservatism in order to be sure of their effectiveness. By confirming laboratory studies with in-field testing, the response of URM buildings to earthquake forces can be truly understood and therefore an effective assessment can be undertaken, eliminating the need for excessive conservatism. This will in turn save the country millions of dollars through cost-effective design solutions and reduced remedial costs of URM buildings.

Section Five: Host Tertiary Education Institution Support

1. Host Tertiary Education Institution

1.1 Department Status and Competencies

The Department of Civil and Environmental Engineering at the University of Auckland recently commemorated its 50th anniversary, and has approximately 31 members of faculty. Their expertise is in 5 broad categories of structural engineering, geotechnical engineering, fluid and water engineering, transportation engineering, and construction management. The department's academic staff are supported by approximately 12 technical staff.

The department's staff have lived in a board range of countries and have an extensive network of relationships with universities and research groups around the globe. Many of the senior staff enjoy international reputations in their chosen fields and continue to receive recognition from their peers for their services to New Zealand.

The department has a long history of research, and has graduated many engineers who have later become prominent nationally and internationally. Two examples are Dr John Hood, currently Vice-Chancellor of Oxford University and Chris Liddell, Chief Financial Officer at Microsoft. The department enjoys a close relationship with its alumni and with its professional and wider community. It has an Industry Advisory Group composed of pre-eminent members of the civil design and construction industry.

A recent Government performance assessment of all New Zealand's academic researchers ranked the Facility of Engineering at the University of Auckland as the highest performing facility in the leading research-led university in the country. Since its establishment in 1952 the department has grown into the largest civil and environmental engineering department in New Zealand.

1.2 Department Facilities and Equipment

The department has a wide range of laboratories associated with its 5 research groups, but the facilities most relevant to this proposal are the Mobile Field Laboratory, the Data Visualisation Laboratory, the Civil Test Hall, and the Civil Materials Laboratory.

The Mobile Field Laboratory (MFL) is currently being developed in conjunction with this research proposal. The department currently has an APS Dynamic ElectroSeis shaker, amplifier, and the associated sensors, data loggers and auxiliary equipment. With the current equipment, in-field testing of small scale structural elements, such as masonry walls, is possible. As a greater amount of sophisticated equipment is added to the Mobile Field Laboratory, the scale of testing will increase concordantly, with the ultimate goal of testing a full scale in-situ URM building until failure. It is currently envisaged that the MFL will comprise the following primary equipment at the time of a full scale test:

- 6 MK-140 eccentric mass shakers (from ANCO Engineers)
- 100-200 accelerometers, lvdts, strain gauges and data loggers
- A vehicle, such a van, to house the servers, data loggers and communication satellites

The Data Visualisation Laboratory (DVL) is the communication portal (hub) for the faculty's activities in the New Zealand Network for Earthquake Engineering Simulation (NZNEES) project (http://www.nznees.auckland.ac.nz). The DVL has a direct link to the government funded KAREN programme which provides a 10 GB connection nationally and 1 GB connection internationally. This allows the sharing of experimental data internationally through a connection with the US Network for Earthquake Engineering Simulation (NEES). Additionally, it enables remote participation and collaboration of experimental testing, whereby tests can be remotely operated and conducted at laboratories throughout the world using these facilities. Specifically, the DVL contains five large TV screens, audio and visual equipment, and many computers in order to monitor, record and control remote experiments taking place in overseas laboratories.

The Civil Test Hall is a large laboratory containing facilities for large scale structural testing.
The test hall is equipped with a large rigid concrete strong floor and reaction wall which is ideal for testing full scale structural elements and subassemblies. The laboratory is predominantly used to conduct pseudo-static tests with a wide variety of hydraulic jacks and a small scale shake table.

The Civil Materials Laboratory includes facilities to test small scale units and more specifically to obtain material properties. The lab includes facilities to test masonry prisms and determine material properties of bricks and mortar which must be established before undertaking in-field testing.

1.3 Research Group Status and Experience

The structural engineering research group is considered an international leader in structural engineering research, specifically recognised for their competency in earthquake engineering. This is achieved by extending existing seismic dynamics and structural materials expertise through international research collaborations and strong interaction with structural engineering and construction industries within New Zealand. Many staff also hold important positions in New Zealand's structural engineering industry organisations.

The structural engineering and geotechnical engineering research groups work closely together on subjects associated with earthquake engineering. A committed strategy within this wider group is to be a leading proponent in the use of advanced digital networks to transfer experimental data internationally. The research group is working closely with similar groups in the United States, United Kingdom, Taiwan and China, with a particular focus on collaboration within the framework of the US Network for Earthquake Engineering Simulation (NEES).

1.4 Mentor Status and Experience

The seismic response of masonry structures is a subject area that Associate Professor Jason Ingham has been researching since 1996. Principal supervision of this project will be provided by AP Ingham and will be assisted by Dr. Piotr Omenzetter with the support of other departmental researchers.

Jason completed his PhD at the University of California at San Diego on the seismic retrofit and redesign of reinforced concrete freeway bridges, in response to several major earthquakes in California. Jason has received several international awards for his research on aspects of the seismic response of masonry structures. Jason's previous doctoral students have also received a number of best paper or best thesis awards, supplemented by other forms of recognition for the calibre of their research. Brief details include:

Year	Details	Awardee
2000	Alan H. Yorkdale Memorial Award, American Society for the Testing of Materials (ASTM)	Ingham and PhD student Laursen
2003	TMS Journal Outstanding Paper Award, The Masonry Society (USA)	Ingham and PhD student Voon
2003	University of Auckland Best Doctoral Thesis Award	PhD student Laursen
2004	New Zealand Society of Earthquake Engineering best student paper award	PhD student Brooke
2006	New Zealand Concrete Society (NZCS) Sandy Cormack Award for best conference paper	Ingham and PhD student Brooke
2006	TMS Best Thesis Award, The Masonry Society (USA)	PhD student Wight

AP Ingham is currently the Principal Investigator of a $3.6M project funded by the Foundation of Research Science and Technology that is developing seismic retrofit solutions for New Zealand's earthquake risk multi-storey building stock.

Piotr graduated with ME from Technical University of Gdansk, Poland, in 1994. Piotr completed his PhD at the University of Tokyo, Japan on aerodynamics of long span bridges in 1999 before accepting a lecturer position at the University of Auckland. Piotr is the principal investigator of the development of the Mobile Testing Laboratory and has been a supervisor of two PhD students involved in earthquake research.

2. Proposed Mentoring and Intellectual Support Plan

Mentoring will be provided by the supervisory team of Associate Professor Ingham, Dr. Piotr Omenzetter and their colleagues from within the department, complimented by the Seismic Retrofit Research Board (SRRB), who will provide valuable input on practitioner aspects of the construction industry. Aaron will also be supported by an international mentoring group, comprising Associate Professor Michael Griffith of the University of Adelaide and Dr Franklin Moon of the University of Drexel. Michael is currently the head of civil engineering at Adelaide and fronts many research projects, including a focus on 'ductile fibre reinforced plastic retrofit of concrete frames subject to static and earthquake loading'. Franklin is a senior lecturer and researcher at Drexel and has a particular interest in full-scale testing of buildings under earthquake simulated loading. Both Michael and Franklin have years of experience and have published leading international articles in earthquake research and will serve as valuable international support for Aaron.

It is intended to ensure Aaron's study is at the forefront of international research through regular attendance and presentation at earthquake engineering and masonry conferences in both New Zealand and internationally. It is also envisaged that Aaron will publish articles in pre-eminent international journals that are peer-reviewed by leading research fellows.

3. Other Comments

N/A

4. Does the Applicant Have the Required Prerequisite Qualification?

Aaron Wilson has recently completed the final semester of his Bachelor of Engineering degree and will graduate in May 2007. Based on performance during previous semesters he is highly likely to receive first class honours, being the pre-requisite for direct entry into the Ph.D. program at the University of Auckland (see attached transcript).

Curriculum Vitae of Primary Supervisor

(Maximum of two pages)

Full name: Jason Ingham

Present position: Associate Professor

Present employer: University of Auckland

Present work address: Department of Civil and Environmental Engineering
The University of Auckland, Private Bag 92019
Auckland Mail Centre, Auckland 1142

Academic qualifications:
2005 MBA, The University of Auckland
2002 GradDipBus (Administration), The University of Auckland
1995 PhD (Structural Engineering), University of California at San Diego
1991 ME (Distinction), Civil Engineering, The University of Auckland
1989 BE (Honours), Civil Engineering, The University of Auckland

Years as a practising researcher: 17

Honours/distinctions/membership of societies, institutions, committees:
2006 New Zealand Concrete Society Sandy Cormack Award for best conference paper
2006 TMS Best Thesis Award (as supervisor of Dr Gavin Wight), The Masonry Society (USA)
2004 Boston Consulting Group Integrated Strategy Award, The University of Auckland
2003 TMS Journal Outstanding Paper Award, The Masonry Society (USA)
2003 Finalist, Young Engineer of the Year, Institute of Professional Engineers New Zealand
2000 Alan H. Yorkdale Memorial Award, American Society for the Testing of Materials (ASTM)

2005-2006 NZ Representative, I.Struct.E Research Panel (UK)
2003-2006 Panelist, Earthquake Commission Research Foundation
1996-2005 Committee, IPENZ Auckland Structural Group
1997-1998, 2001-2003 Council, New Zealand Concrete Society
1997-2003 Executive Officer, New Zealand Concrete Masonry Association
2001-2006 Committee, NZS 4230 'The Design of Masonry Structures'
2005-2006 Committee, NZS 4229 'Masonry structures not requiring specific engineering design'
2001-2006 Corresponding Member, Masonry Standards Joint Committee (USA)

Professional positions held:
Senior Lecturer, 2/2003-10/2005; CCANZ Fellow, The University of Auckland, 7/1995-2/2003

Present research/professional speciality:
Seismic design of reinforced concrete and masonry, rocking response of self-centering structures, strut and tie design of concrete structures, influence of loading history on structural performance, reinforcement mechanical anchorage systems, structural seismic retrofit.

Number of refereed publications: 27 journal papers & 75 conference papers
Number of patents: 0
Number of significant publications not included in the above: 37 Technical Reports

Number of research qualifications at Level 7 NQF/Hons supervised to completion: 21
Number of post-graduate theses supervised to completion: PhD: 4 Masters: 7
Number of post-graduate theses examined: PhD: 3 Masters: 1

List of major achievements pertinent to the supervision of this research proposal:

1. Major publications (in the last five years).

Journal articles

2006. LAURSEN, P. T., WIGHT, G., **INGHAM, J. M.** 'Assessing Creep and Shrinkage Losses in Post-tensioned Concrete Masonry', *ACI Material Journal, 103, 6, Nov-Dec*, 427-435.

2006. VOON, K. C., **INGHAM, J. M.** 'Shear Design of Concrete Masonry using NZS 4230:2004' *Journal of the Structural Engineering Society of New Zealand, 19, 1, 20-25.*

2006. WIGHT, G. D., **INGHAM, J. M.**, KOWALSKY, M. J. 'Shaketable Testing of Rectangular Post-tensioned Concrete Masonry Walls' *ACI Structural Journal 103, 4*, July-August, 587-595.

2006. **INGHAM, J. M.** 'Current seismic retrofit research in New Zealand', *The Structural Engineer, 84, 11*, June 6, 20-21

2006. VOON, K. C., **INGHAM, J. M.** 'Experimental in-plane shear strength investigation of reinforced concrete masonry walls' *ASCE Journal of Structural Engineering*, 132, 3, 400-408.

2004. LAURSEN, P. T., **INGHAM, J. M.** 'Structural Testing of Enhanced Post-Tensioned Concrete Masonry Walls' *ACI Structural Journal, 101, 6, Nov-Dec,* 852-862.

2004. LAURSEN, P. T., **INGHAM, J. M.** 'Structural Testing of Large-Scale Post-Tensioned Concrete Masonry Walls' *ASCE Journal of Structural Engineering, 130, 10,* 1497-1505.

Conference articles

2006. RUSSELL, A. P., **INGHAM, J. M.**, GRIFFITH, M. C., 'Comparing New Zealand's Unreinforced Masonry Details with those of Other Seismically Active Countries', Paper No. 42, 7th International Masonry Conference, London, England, 30 October – 1 November.

2006. SCHOFIELD, H., **INGHAM, J. M.**, PAMPANIN, S. 'Critical Earthquake Risk detailing in New Zealand's Multi-storey building stock: Understanding and improving the current perception', Conference of the New Zealand Society of Earthquake Engineering, Napier, Paper Number 39, March 10-12.

2005. VOON, K.C., **INGHAM, J. M.** 'Experimental Study of Partially Grouted Concrete Masonry Walls with Openings', 10th Canadian Masonry Symposium, Banff, Alberta, June 8-12.

2004. WIGHT, G., **INGHAM, J. M.**, KOWALSKY, M. 'Shake Table Testing of Post-tensioned Concrete Masonry Walls', *New Zealand Concrete Industries Conference, 16-19 September, Queenstown, New Zealand.*

2004. VOON, K. C., **INGHAM, J. M.** 'Shear Strength of Concrete Masonry Walls' *7th Australasian Masonry Conference, Newcastle, Australia, July 13-16, 102-111.*

2002. VOON, K. C., **INGHAM, J. M.** 'Experimental Study of the Shear Strength of Reinforced Concrete Masonry Walls' *6th International Masonry Conference, London*, *United Kingdom, 4-6 November,* 536-544.

2. Major achievements in commercial, social and environmental areas (including evidence of relationship management, business, commercial and project management expertise, if relevant).

Associate Professor Ingham has two business qualifications, has completed over 20 commercial consulting projects, and has serves on the committees of two New Zealand masonry design standards. He has been an executive level member of several New Zealand societies related to earthquake engineering, structural engineering, and masonry. He has received substantial research funding from private industry, particularly in the concrete and masonry industries.

3. Demonstration of relationships with end-users.

In addition to serving at executive level on several professional organisations, AP Ingham has presented 8 nationwide seminars to practicing structural engineers and has assisted in the organisation of 10 industry conferences since 1997. He typically assembles an Industry Advisory Group for his research projects, as exemplified by the Seismic Retrofit Research Board (SRRB) assembled for the $3.6M 'Seismic Retrofit Solutions' project (www.retrofitsolutions.org.nz).