Prioritising research into the seismic performance of reinforced concrete

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ABSTRACT: The seismic performance of some reinforced concrete elements and systems in the 22nd February 2011 Christchurch earthquake raised issues which need researching and resolving. Some of these form part of the recommendations of the Canterbury Earthquakes Royal Commission. The authors, in their respective roles within MBIE and the Natural Hazards Research Platform, have been looking into the resources, capability and capacity within New Zealand and internationally to address these issues. There is a need for collaboration both within New Zealand and internationally to optimise research efforts. This paper describes the progress being made, and the plans so far with respect to the design and performance of floor diaphragms and highly-loaded walls, in particular.

1 INTRODUCTION

The Canterbury earthquake sequence has caused widespread damage to New Zealand's second largest urban environment with significant loss of life and injuries and economic loss estimates equivalent to approximately 20% of national GDP. Total losses are among the highest incurred internationally for natural hazard events. However, it is also one of the most recorded and documented earthquakes ever. An extraordinary amount of data has been collected, from seismicity recordings, land damage, building damage, topographic changes, infrastructure breakages, etc. While efforts have been prioritised to facilitate the recovery, it is important for us all to learn from this, both for the rebuild and for future development and building both throughout New Zealand and overseas. This raises the importance of research and the role researchers play in the gathering and analysis of data, researching solutions to emerging issues and in bringing new knowledge to practice. Many international researchers are keen to collaborate with us and share in the lessons for translation into their home-country practices.

The need for research covers a wide range of topics including: faults, seismicity, liquefaction, ground remediation, foundations and performance of buildings. The Canterbury Earthquake Royal Commission, CERC, identified many of these issues and recommended that research be carried out.

It is important to recognise that CERC's (2012) recommendations do not imply an absence of existing or ongoing research in these areas. In fact, a considerable amount of research has been completed and more is underway within universities, Crown Research Institutes, private research organisations, and within consultancies. However, the recommendations do highlight areas where additional research effort is needed.

The Ministry of Business, Innovation and Employment (MBIE) has accepted the responsibility for many of these research recommendations, and there is an expectation within government and the community that the recommendations from CERC will be followed up in a reasonable timeframe.

This has created a challenge for MBIE which is still being worked through. These difficulties are not caused by unwillingness on the part of researchers, but more reflect the ways in which our research is

funded and carried out within New Zealand. MBIE uses standard, government procurement procedures for goods and services including research. This would typically involve development of a project brief, going to market via the Government's Electronic Tendering Service (GETS) with an expression of interest and/or request for proposal. Tenders complying with the Request for Proposal are evaluated against predefined criteria, and a supplier selected. A contract is then prepared listing milestones, deliverables, deliverable dates and payment dates.

This can work well where there is a well-defined problem to be solved, a single funding agency, and a number of suppliers with capacity and capability to deliver the service.

There has been significant change over the years in the way research is carried out. During the mid-to-late twentieth century, there was much greater centralisation of research undertaken by government agencies and the universities. In more recent times, research has become much more devolved - with funding being provided through different government agencies, usually based on proposals being made by various researchers depending on their particular area of expertise and interest. Research projects may have multiple funders and multiple research organisations delivering the research.

We now have specific questions to address based on CERC's recommendations and engineering practitioners wanting answers to specific questions - including a number on the performance of reinforced-concrete buildings:

- Effects of rate and sequence of loading rates on reinforced-concrete elements
- Effect of vertical acceleration
- Stiffness degradation
- Floor diaphragm behaviour
- Concrete wall and beam behaviour

The incentives, capacity and capability available for researchers working within New Zealand may not be able to address all these questions in a timely manner. Many of these research questions are also being considered internationally, and MBIE is therefore keen to see international research cooperation where appropriate so that we can leverage off work done elsewhere. It is also keen to see greater input at the front end from practitioners to help ensure that research is directed towards areas of most relevance to practitioners and is undertaken in a manner that will help resolve current knowledge gaps.

2 OVERVIEW OF RESEARCH IN NEW ZEALAND

Research is carried out in a range of institutions and organisations in New Zealand. These include; universities, Crown Research Institutes, research associations and public and private companies.

There are also multiple funders of research. With regard to funding for research on earthquake engineering in New Zealand, the main sources are listed below.

2.1 MBIE Science, Skills and Innovation Group (SSI)

SSI was previously the Foundation for Research, Science and Technology (FRST) which merged with the Ministry of Research Science and Technology (MoRST) to create the Ministry of Science and Innovation (MSI) in 2011 before being incorporated into MBIE.

Most of the MBIE SSI investment in hazards and infrastructure-related research in New Zealand is through the Natural Hazards Research Platform (NHRP, www.naturalhazards.org.nz) and, indirectly, through core funding to GNS and NIWA which also supports the NHRP.

The NHRP was created in October 2009 and was the first pilot of a funding model that was intended to provide long-term (10-year), stable funding to researchers in key areas of importance for New Zealand. The model devolved the responsibility to identify key research questions and manage the contracting and reporting of the research to the research providers with input from industry and oversight by MBIE. GNS Science, NIWA, Opus International Consultants Ltd. (Opus), Massey

University, University of Canterbury and University of Auckland are the original platform members and, in addition, there are subcontracts to an additional 20 or so agencies or research groups. The Platform Management Team consisting of technical people not directly involved in the science represent their organisations and are charged with decision-making with respect to allocations in consideration of a wider group input.

The initial funding was around $14 million per year, but has increased to around $17 m per year subsequent to the Canterbury earthquakes. This includes funding to the participating Crown Research Institutes ("Core Funding"). The NHRP funding is across five themes:

- Geological hazard models
- Predicting weather, flood, and coastal hazards
- Developing regional and national risk evaluation models
- Societal resilience: social, cultural, economic and planning factors
- Resilient buildings and infrastructure

Funding is split between negotiated and contestable tranches, and the next contestable round will begin in 2015. Individual research contracts allocated to members of the NHRP or contractors typically run over a three-year period.

While the NHRP undertakes some infrastructure research as it relates to hazards, some is funded directly by MBIE's 2012 "Hazards & Infrastructure" contest.

2.2 **The University System**

Universities are funded through a number of mechanisms. The Tertiary Education Commission (TEC) provides the base funding for universities which covers about 40% of their operating costs. Other income sources for universities are fees and research contracts (including from NHRP, MBIE, EQC and BRANZ).

2.3 **The Earthquake Commission (EQC)**

One of the Earthquake Commission's roles is to facilitate research about natural disaster damage and methods of reducing or preventing natural disaster damage, with the aim of improving knowledge and professional practices.

EQC directly funds a number of university faculty positions in a range of disciplines relevant to hazard risk management and disaster resilience. These include natural hazards and engineering at the University of Canterbury, seismic studies and economics of disasters at Victoria, social science and planning at Massey, and volcanic risk and engineering at the University of Auckland.

Every two years, EQC carries out a contestable grants programme of public good research aligned to its research strategy. Separate funds also exist for support to post-graduate students, for responding to short-term needs, and to provide opportunities for leveraging research activities across other funders.

EQC has active 'research to practice' and 'sector capability' programmes working with all groups with responsibilities in hazard risk management, is principal funder of GeoNet (the national hazard monitoring system), and has invested substantial funds into research on liquefaction susceptibility and ground stabilisation in Canterbury subsequent to the earthquakes.

EQC also assists in the dissemination of relevant research results and experience by sponsoring selected technical publications, meetings and conferences.

2.4 **BRANZ Levy**

BRANZ Inc. receives the Building Research Levy on building consents of $20,000 or more. The Levy is invested in research both within BRANZ and through external research providers. The overall investment framework is governed by Building a Better New Zealand – the industry research strategy

developed by MBIE, CIC, CSG and BRANZ in 2013. Within this strategy there is a strong focus on resilience and earthquake engineering as it applies to both new building but also existing stock. In addition to its research role, BRANZ also acts as an important information conduit to industry for both its own, and others, research – its BUILD magazine, for example, is the most widely-read publication in the industry. BRANZ is part of MBIE's Engineering Advisory Group (EAG) and aims to ensure that its own research and that commissioned externally by Building Research Levy is conveyed back to industry through this key platform.

BRANZ is also funding two PHD Scholarships that relate to earthquake engineering.

2.5 MBIE Building Systems Performance Branch (BSP)

BSP has a modest research budget which is available to commission research to support the development and maintenance of the Building Code and supporting documents. This budget has been increased to help fund the research recommendations arising from the Canterbury earthquakes.

3 PROGRESSING REINFORCED CONCRETE RESEARCH

A considerable amount of engineering research has been completed and more is underway particularly within Universities. This research is a mix of NHRP and University funding. Some of this research is actually addressing specific research recommendations while other parts are partially addressing specific recommendations.

As noted earlier, a standard tendering approach is not well suited to a complex matrix of funders, and projects spread among providers. Universities are also constrained in the way they can respond to the market. They are primarily set up to teach and do research. Academic freedom and curiosity-driven research are important aspects of the way they operate. Researchers with specific areas of interest attract students who are an essential part of the research process. The availability of students and supervisors and their interest areas may not always align well with the needs and timeframes of the market.

New Zealand is a small country and has limited resources. The main structural engineering laboratories are those at the engineering faculties at the University of Auckland and the University of Canterbury. The existing laboratories date from the 1960s and have not had major investment in new equipment over the last few decades. Both universities are now redeveloping their facilities subsequent to the earthquake damage at Canterbury and the partial relocation of the engineering school in Auckland.

This will improve capability and is important to attract high-quality staff and students. However, the development of large-scale, dynamic test facilities (such as a large shake-table) is unlikely to be economically viable in NZ in the foreseeable future.

Other organisations also have structural engineering facilities (Opus, BRANZ and Holmes Consulting Group). However, these face the same economic barriers to investment in large-scale, dynamic test facilities as the universities.

The approach MBIE has taken in this case is to work collaboratively with the NHRP, EQC, BRANZ and the researcher community to identify opportunities to leverage both existing projects and funding for new high-priority research.

4 PROGRESS TO DATE

Three workshops have been held with researchers along with members of MBIE's Engineering Advisory Group and the Buildings Theme Leader from the NHRP to identify what research is either currently underway or complete that addresses research recommendations arising from the Canterbury earthquakes. The second two focussed on the recommendations relating to the performance of reinforced concrete buildings.

The third workshop was organised and facilitated by the University of Canterbury Quake Centre (ucQC) on behalf of MBIE. ucQC is a university/industry/government partnership that draws together expertise in earthquake engineering to benefit Christchurch and New Zealand. The Centre is focused on meeting the identified needs of the industry and the community, in terms of training, compiling best practice, actively disseminating information, identifying levels of risk, and providing new solutions to create resilient infrastructure and communities. MBIE sees an opportunity for ucQC to utilise its close links to both engineering schools to provide programme-level oversight and management on the reinforced concrete research recommendations, and potentially minimise administrative demands on the key researchers.

The outcomes of the third workshop are an improved understanding of the research underway, how well this addresses the knowledge gaps, and what additional research is likely to be needed. The ucQC has been working with the researchers to develop initial project proposals outlining the proposed research team, aims of the research, general methodology, timing and costs.

The projects are listed in Table 1.

The projects are currently being reviewed by MBIE's Engineering Advisory Group and will also be shared with leading international researchers with similar research interest to see if there are opportunities for collaboration.

Following this process, MBIE intends to contract ucQC (via subcontracts to the researchers) to deliver packages of work. The extent and timing of the programme will be subject to the availability of funds and high-priority projects will be advanced first.

Table 1. Existing and Proposed Projects on Seismic Performance of Reinforced Concrete

Topic	Project Manager	Status	Funder	Duration (years) *
Lightly-reinforced concrete walls	Rick Henry	Existing	NHRP	3
Biaxial displacement of walls	Des Bull	New	MBIE	3
Elongations of walls and wall-to-floor interaction	Rick Henry	Existing	NHRP	3
Effects of diaphragm interaction on coupling beam strength and distribution and magnitude of shear forces in multi-storey coupled reinforced concrete walls	Jason Ingham	New	MBIE	2
Torsion and flexure in shear cores	Jason Ingham	New	MBIE	2
Rate of Loading / Concrete Ageing Strength	Alistair Russell	New	MBIE	0.5
Singly-Reinforced Walls – Best Practice Guidelines	Alistair Russell	New	MBIE	2
Diaphragm design handbook	Stefano Pampanin	New & Existing	MBIE	2.5

* Caveat - research findings may result in additional validation research being required possibly through large-scale dynamic testing.

5.1 Wider New Zealand interest in collaboration

MBIE SSI has a role in facilitating international collaboration through a number of international science agreements (e.g., NZ/Japan, NZ/USA), often bringing New Zealand expertise to the table through the Natural Hazards Research Platform. As a result, the Group and the wider hazards research sector have some strong connections to key institutions offshore on which we can build. Strengthening our international connections would have significant value in helping us access overseas research and research facilities where there is limited or no capacity in New Zealand.

The Ministry of Foreign Affairs and Trade also has a strong interest in international collaboration in the area of disaster risk management and have a "Special Envoy Disaster Risk Management" (Phillip Gibson) to manage their interests. In diplomatic terms, cooperation on disaster risk management is welcomed by most governments regardless of the closeness or otherwise of diplomatic relations.

5 MBIE CHAIR IN EARTHQUAKE ENGINEERING

During the last quarter of 2013, MBIE realised that it would be beneficial to strengthen its ties with academia in engineering schools in New Zealand and overseas. This would bolster its access to high-quality engineering advice and facilitate an improved understanding by academic researchers of MBIE's needs as the Ministry progresses through the Royal Commission recommendations and in the longer term.

To assist in fostering improved collaboration between New Zealand and international researchers and between academics and practitioners, MBIE agreed to part-fund a new "Chair in Earthquake Engineering" at the University of Auckland. Both MBIE and the University are delighted that Professor Ken Elwood, currently a structural engineering professor from the University of British Columbia, has accepted this position and will be commencing here in New Zealand from August 2014. He studied at the University of California Berkeley under Professor Jack Moehle, has been very active with North American professional organisations such as EERI, ACI, ATC and ASCE, and has a long-standing interest in New Zealand engineering issues. Some conference attendees may have met him while he was on sabbatical in Auckland during 2010 or during the February 2011 response in Christchurch where he provided valuable help with the "critical building" operations. He has since been back on several occasions to, among other tasks, provide advice to MBIE on the reinforced concrete research shown in Table 1.

The Chair will participate in teaching and research at the University, but will also work on specific initiatives for MBIE to help it deliver on its regulatory responsibilities around the Building Code and supporting documents. Some of the activities the Chair will be involved with include:

- Assisting MBIE to define an ongoing programme of research to support the development and maintenance of the Building Code Clause B1:Structure.
- Assisting MBIE to engage with The University of Auckland, the University of Canterbury and other organisations to progress the research projects identified in the research plan.
- Carry out research on earthquake engineering individually and/or in collaboration with other researchers from the University of Auckland or other research institutions, that addresses MBIE's identified needs relating to clause B1:Structure.
- Actively facilitate cooperation between researchers in NZ and overseas to ensure MBIE has access to the latest research results on structural issues relating to B1 Structure.
- Provide input to MBIE's Engineering Advisory Group (EAG) on matters relating to B1: Structure.
- Actively participation in New Zealand and overseas technical committees that align with MBIE's needs for technical information for Clause B1:Structure and supporting documents, and
- Provide advice on specific projects as agreed with MBIE.

Professor Elwood has already facilitated a meeting between MBIE and leading international researchers at the American Concrete Institute's conference in Arizona in October 2013. An outcome of this is a proposal for international collaboration potentially between NZ, USA, Japan, Italy and Chile. This will be facilitated through a series of international research workshops on the seismic performance reinforced concrete, with the first being organised for May or October 2014 in the USA.

6 CONCLUSIONS

Our experience has highlighted the desirability of an integrated overview of the earthquake engineering research being undertaken in NZ. This would improve visibility of current activities and assist funders, practitioners and stakeholders identify where research expertise resides.

It would also improve the ability of researchers and funders to match the needs of practitioners; identify where there are knowledge gaps, and provide more robust methods of analysis to design New Zealand buildings that can economically and appropriately withstand the natural hazards to which they will be exposed during their lifetimes.

New Zealand has a small pool of engineering resources. This makes the need to collaborate more effectively, both within the profession in New Zealand and with international researchers and professional bodies, much more important. In the wake of the Royal Commission recommendations, the needs of the Canterbury rebuild, and the response to the identification of earthquake-prone buildings throughout New Zealand, the same key people are being assigned to an increasing number of tasks. There is a need to broaden the knowledge and experience base and improve connections and collaboration to ensure that we get the most out of our limited resources.

Leveraging international developments and research and closer collaboration between practitioners and academics to get the answers needed by engineers, developers and ultimately the public of New Zealand will be key.

REFERENCES

Canterbury Earthquakes Royal Commission. 2012. Final Report Parts 1 and 2.