International Research (Project No.: 28W-03)

Project name: **Enabling Smart Retrofit to Enhance Seismic Resilience: Japan and NZ Case Studies**
Principal Investigator: Timothy J. Sullivan
Affiliation: University of Canterbury
Name of DPRI collaborative researcher: Masahiro Kurata
Research period: 4 1, 2016 ~ 3 31, 2018
Research location: DPRI, Kyoto University and Quake Center, University of Canterbury
Number of participants in the collaborative research: 2 Associate Professors and 1 Post-doc from UC (Trevor Yeow)
- Number of graduate students: 2 Masters (Fransiscus Assisi and Joshua Mulligan) and 1 PhD student (Amir Orumiyehei) from UC, and 1 Masters (Tadahisa Takeda) and 2 PhD students (Lei Zhang and Giuseppe Marzano) from DPRI
- Participation role of graduate students: One Masters student from UC assessed a 22 storey case study building and developing smart retrofit/rehabilitation options. A second Masters student from UC developed experimental testing plans for non-structural partition walls. The PhD student from UC undertook design and loss assessment, with assistance of a post-doc, of typical steel buildings. The students from DPRI assessed the 13 storey case study building in Japan and collected cost data for non-structural components.

Anticipated impact for research and education

The research project has examined means by which cost-effective retrofit and/or rehabilitation solutions can be identified. Through examination of a number of case-study buildings subject to different ground motions, and then by estimating likely losses with retrofit and/or rehabilitation measures, the relative benefits of different interventions has been highlighted. The findings indicate that provision of non-structural elements with improved detailing may be the most cost-effective strategy for building retrofit and/or rehabilitation. Design considerations could be made in relation to the location of non-structural elements so that they do not interfere with inspection and repair of structural elements post-earthquake. The research has also shown that the impact of aftershocks can have a significant impact on the perceived performance of different retrofit/rehabilitation options.
The results from loss assessment of typical Japanese buildings has also be used to trial and develop options for simplified loss assessment, so that it can be used for the smart seismic retrofit of buildings. By identifying a simplified method that offers an acceptable level of accuracy the project has successfully developed a practice-oriented method for smart retrofit, which could be developed further in years to come.
The research findings have also prompted the development and testing (currently on-going in New Zealand) of innovative non-structural partition wall detailing strategies. The findings of such research will inform the industry and future engineers at the University of Canterbury about means of detailing non-structural walls to provide more resilient buildings and communities.

Research report

(1) Purpose

This research project was formulated in recognition that traditional seismic assessment, retrofit and/or rehabilitation methodologies may not always lead to the most cost-effective use of resources. As such, the objective of this research was to develop tools and technologies to allow, via a relatively simplified methodology, the identification of retrofit and/or rehabilitation solutions that reduce likely monetary losses and downtime caused by earthquakes, and exhibit minimum disturbance to building users. The research project has also served the purpose of facilitating stimulating collaboration between NZ and Japanese graduate students and researchers, permitting exciting research experiences and cultural exchanges with Japanese and New Zealand counterparts. This will hopefully serve as the starting point for long-term collaboration between researchers.

(2) Summary of research progress

The first year of this project saw efforts made to collect data on the seismic performance of buildings in the Canterbury earthquakes, and reflect on the lessons to be learnt regarding cost effective retrofit. For New Zealand, two large datasets of damage data were obtained, one from the Earthquake Commission (EQC) and the other from Lin et al. (2016). However, neither database appears to contain a considerable amount of useful data on the seismic performance of steel buildings. As such, the literature related to the performance of steel buildings in the Canterbury earthquakes was examined and the work by Clifton et al. (2011) provided a useful summary of steel building performance. One building that was described in the work of Clifton et al. (2011), known as the Pacific Tower building, was selected as a case study building for trial application of advanced assessment and cost-effective retrofit strategies. The case study building is a 22-storey eccentrically-braced frame (EBF) structure. During the February 2011 earthquake it suffered from permanent deformations, a fractured link in the 6th floor (Figure 2.10) and reasonably extensive non-structural damage. A full set of drawings of the building have been obtained from the Christchurch City Council and a non-linear model of the structure developed in Ruaumoko (Carr, 2017).

Similarly in Japan, work was undertaken to identify a typical steel building that can be used to investigate the impact of different retrofit and rehabilitation strategies on seismic losses. To this extent, a 13-storey steel frame building with buckling-restrained braces (BRB) was modelled and subject to non-linear dynamic analyses as the first stage of the loss assessment process.

In the course of the research, the possibility of constructing and testing GIB devices fit to a 3-storey steel frame in Japan was assessed. It was found that the GIB system would not be suited for the 3-storey frame because of the low P-delta demands on the system. As such, it was deemed impractical to undertake shake table testing of this solution in this project.

In the final year a study into the impact of different retrofit and/or rehabilitation strategies of the 22 storey steel EBF building was completed with consideration of retrofit and/or rehabilitation strategies that target non-structural elements because indications from past research and also from the Canterbury earthquakes suggests that non-structural elements are likely to be the main source of loss. The work being undertaken in Japan on the 13-storey steel building was further developed and a simplified procedure for loss estimation was proposed, so that cost-effective retrofit and/or rehabilitation strategies could be quickly identified.

In the final months of the project, experimental plans for testing of light-weight partition walls were developed and the experimental set-up for testing walls was established. Co-funding has now been sourced from within New Zealand to continue research into low-damage non-structural partition walls, highlighting the benefit and value of this research project.

(3) Summary of research findings

The findings of this research indicate that provision of non-structural elements with improved detailing may be the most cost-effective strategy for building retrofit and/or rehabilitation. This includes consideration in relation to the location of non-structural elements so that they do not interfere with inspection and repair of structural elements post-earthquake. The research has also shown that the impact of aftershocks can have a significant impact on the perceived performance of different retrofit/rehabilitation options. Furthermore, by developing a simplified method for estimation of repair costs the project has successfully developed a practice-oriented method for smart retrofit, which could be developed further in years to come.

(4) Publications of research findings

Sullivan, T.J., Arifin, F.A., MacRae, G.A., Kurata, M., and Takeda, T., (2018) “Cost-effective consideration of non-structural elements: Lessons from the Canterbury earthquakes” Proceedings, 16th European Conference on Earthquake Engineering, Thessaloniki, Greece, paper 10928.

Takeda, T., Arifin, F.A., Kurata, M., Sullivan, T.J. and MacRae, G.A. (2018) “A simplified method to select effective seismic retrofit for steel buildings based on damage cost” Architectural Institute of Japan, Kinki branch meeting.

Arifin, F.A., Sullivan, T.J., MacRae, G.A., Kurata, M., and Takeda, T., (2018) “Considering likely repair costs for non-structural elements during seismic design, retrofit and/or rehabilitation: The case of a 22-Storey Steel EBF Building” Journal of Earthquake Engineering, *in preparation*.