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
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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: 1 Masters (Fransiscus Assisi) 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: The Masters student from UC is assessing the 22 storey case study building and developing smart retrofit/rehabilitation options. The PhD student from UC is undertaking design and loss assessment, with assistance of post-doc, of typical steel buildings. The students from DPRI are assessing the 13 storey case study building in Japan and collecting cost data for non-structural components.

FY2016 Implementation status:
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). Non-linear static and dynamic analyses of the structure have been undertaken and sensitivity studies are currently on-going as the impact of various modelling assumptions are investigated. A student from New Zealand visited Japan as part of the research to learn about experimental testing possibilities and the research approach in Japan.
Similarly in Japan, work has been 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) has been modelled and is being subject to non-linear dynamic analyses as the first stage of the loss assessment process. A student from Japan visited New Zealand as part of the research to learn about the loss assessment process and research approach in New Zealand.
In parallel to these activities, work is underway to examine the performance of typical new steel office buildings in New Zealand and assess their likely performance, in terms of losses, in future earthquake events. This work has included collection of drawings for a number of office buildings in Christchurch which are being examined to permit definition of "typical" office buildings that can be subsequently designed, assessed and used to examine effective retrofit measures.
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 is no longer proposed to undertake shake table testing of this solution in this project.

FY2017 Implementation plan

In 2017 the plan is to conclude the study on the 22 storey steel EBF building by completing the sensitivity study on the analyses and then proceeding to investigate the impact of different retrofit and/or rehabilitation strategies. The intention is to consider 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. Options for structural interventions that might improve overall performance will also be considered. In particular, it is envisaged that the use of viscous dampers could be an effective means of reducing losses. The work being undertaken in Japan on the 13-storey steel building will also be developed in a similar manner to identify cost-effective retrofit and/or rehabilitation strategies. By repeating loss assessment for the structures with retrofit and/or rehabilitation measures, the relative benefits of such interventions can be identified. Furthermore, this research will consider the impact of aftershocks on the perceived performance of different retrofit/rehabilitation options. These tasks will permit the completion of Task 2, undertaking cost-benefit analysis to identify effective retrofit or rehabilitation options of NZ and Japanese buildings. These research findings are likely to be submitted for publication within an international journal at the end of the year.

The research findings are also expected to prompt the development of innovative non-structural retrofit and rehabilitation strategies that should be the focus of subsequent analytical and experimental research. This could include numerical modelling and analysis, as well as quasi-static tests conducted at the University of Canterbury and shake table testing at DPRI.

The results from loss assessment of the typical New Zealand buildings will also be used to trial different simplified methods for loss assessment and develop these further for the smart seismic retrofit of buildings. The performance of these simplified methods will be gauged by comparing the loss estimates they produce with those obtained using refined assessment approaches. By identifying a simplified method that offers an acceptable level of accuracy, the main objective of the project, to develop a practice-oriented method for smart retrofit, will have been achieved.

In 2017 it is expected that DPRI staff will visit the University of Canterbury around August and that University of Canterbury staff will visit DPRI in late November. The main purpose of these visits will be to foster collaboration efforts, with the hope that the DPRI visit to Canterbury in August would coincide with quasi-static testing of non-structural retrofit/rehabilitation measures and, in the instance of the visit to DPRI in late November, dynamic testing of non-structural retrofit solutions.

Carr, A. (2017). 3D RUAUMOKO: inelastic three-dimensional dynamic analysis program. Carr Research Ltd., 41 Cashmere Road, Christchurch 8022, New Zealand.

Clifton, C., Bruneau, M., MacRae, G., Leon, R., & Fussell, A. (2011). Steel structures damage from the Christchurch earthquake series of 2010 and 2011. Bulletin of the New Zealand Society for Earthquake Engineering, 44(4), 297-318.

Lin, S.L., Uma, S.R., King A., Buxton, R., Horspool, N., (2016) “A Compiled and Extensible Database for Building Damage from the 2010–2011 Earthquake Sequence in Canterbury, New Zealand”, GNS Science Report 2016/30.