Final Report: EQC 14/U679 – March 2018

Structural Health Monitoring: From macro to micro, a progressively detailed assessment of structural performance and damage assessment for immediate response to lifetime analysis.

Student Fellow: Mr Eimantas Poskus

Summary:
This final report outlines the work undertaken by Eimantas Poskus during his PhD studies under our supervision. Eimantas has extended our prior work on Structural Health Monitoring (SHM) to apply the techniques to real structural data from experimental specimens, including non-building infrastructure and the key elements of these systems.

Our prior work over the last five years has included the development of a Hysteresis Loop Analysis (HLA) techniques that process accelerometer data from dynamic building response to approximate the hysteretic behaviour of the structure. This technique has been proven effective at tracking the evolution of elastic stiffness throughout an earthquake, which can then provide an estimate of both the location and severity of damage that has occurred within the structure. While this HLA method has shown significant promise, it was previously only applied to simple structures that exhibit a first-mode dominant response. When this approach was applied to more complex multi-level structures with more significant contributions from higher modes, the irregularity in the reconstructed hysteresis loops led to identification errors and less reliable performance of the analysis methodology.

As a result of these identified difficulties, the primary goal of the PhD studies of Mr Eimantas Poskus was to investigate modal separation and filtering methods, to enable the existing identification methods to be applied to complex structures with notable contributions from these higher modes. That goal has been obtained, with a model filtering and successive identification method developed within the PhD thesis. The outcomes of his research will enable more widespread application of these techniques, to enable increased insight into the field performance of a wide range of monitored structures (buildings, bridges etc) during earthquakes.

Introduction:
The use of seismic monitoring systems is increasing, both within New Zealand and worldwide. However, while these systems provide data from a building response, the challenge for engineers and researchers is to provide robust and reliable processing algorithms that are capable of interpreting this data to provide the building owners/tenants and the general public with meaningful information. The processing algorithms must also be robust so that they can be applied to a range of possible structures, from first-mode dominant bridge piers, to multi-level buildings with multi-mode response.

The initial work undertaken by Eimantas focused on the modal decomposition of structural response, using data from the non-linear dynamic response of bridge piers with strong first mode dominance and only minor contributions from the second mode. He then progressed onto validating the model decomposition/filtering methods using non-linear experimental response data from multi-level buildings. This building data was a significantly more stringent test of the identification and filtering methods as there is a higher contribution from higher mode effects and closer spacing between modes, with the inclusion of axial and torsional modes, in addition to the standard flexural modes.

This modal filtering process is an essential step in the overall process of damage identification. Once the different modal contributions to response are determined, several methods of damage identification, based primarily on the Hysteresis Loop Analysis (HLA) method were applied. In essence, the work of Mr Eimantas Poskus is extending the reach of a new, but now well proven, damage identification method.
As detailed in the interim reports, linkages with Tongji University in Shanghai, China (Dr. Baofeng Huang and Professor Shiming Chen) and Dr. Rickey Iihoshi from the R&D department at the Asahi Kasei Homes Corporation in Japan, has provided access to several additional sets of dynamic shake-table data on model structures undergoing notable damage. The dynamic data that we received from the testing at E-Defence, has been analysed by both Dr Zhou (now a postdoc in our group) and Mr Poskus, to determine the efficacy the SHM methods developed by Mr Poskus when applied to building data.

Eimantas has undertaken a range of analyses to improve the robustness of health monitoring algorithms to data with a strong presence of higher mode effects (with closely spaced modes of vibration) and sensor noise. The primary contribution of his work is the development of modal filtering methods to de-couple the contributions of first-mode response from other higher mode effects. He also developed a detailed fibre-model using finite elements and detailed localised behaviour to enable the simulation of realistic non-linear response data. This highly non-linear synthetic response data was used as a validation of the new analysis routines, whereby the forward simulation provides known results, which can then provide a baseline for assessment of the identification, with and without the inclusion of artificially introduced random noise on the simulated response.

**Highlights from this project:**

Eimantas has presented his work via poster and abstract at the New Zealand Society for Earthquake Engineering (NZSEE) annual technical conferences in Rotorua in 2015, Christchurch in 2016 and in Wellington in April 2017.

Eimantas’ initial work on his modal filtering and identification methods has been published in a journal paper in Computer Aided Civil and Infrastructure Engineering (CACAIE). This journal is one of the most highly regarded and highest cited journals in structural engineering. The full citation is:


The final PhD thesis was submitted at the end of 2017, with Eimantas successfully defending his work at the oral examination in early April 2018. In addition, Eimantas is currently working on published each of his key studies as individual journal papers. Two of these are already under review, with an additional two papers in preparation. In total, we anticipate that at least four journal papers will come out of the PhD thesis. A bibliography is included at the end of this report, but it is important to note that the publication of this work is ongoing and this list will be modified as the individual studies complete the peer review process and are accepted for publication.

The additional work on the fibre-model was used as a validation method for the identification and SHM methods developed, using the synthetic non-linear structural response data to analyses algorithm performance across a range of structures. In these cases, where the outputs are known exactly, it is thus possible to quantify the accuracy, something which similar prior works by other groups have not done.

In addition to the work contained with the PhD thesis, we are continuing to investigate options to develop a combined analysis methodology using contributions from the empirical modal decomposition methods used by the instrumentation and analysis group at Yunlin University of Science and Technology (YunTech). Our prior algorithms have typically used a baseline damping ratio to subtract out damping forces from the hysteretic response, but using an iterative, hybrid method bringing in the methods from the group at YunTech may improve the accuracy of identification. Work on this iterative hybrid identification method is continuing and will be the focus of future work.

As mentioned in the 24 month report, the ability to develop detailed, non-linear response data and link to the identified modal damping ratios from the Taiwanese group’s work is an important hybrid approach to SHM which could prove to deliver improved identification of structural parameters and structural damage. As such, the combined methodology may reduce identification error and allow an approach for high-level hysteresis loop analysis. Work is ongoing using the field measurements from China, Japan, and Taiwan will help to validate his methods.

There is significant publishable work that has been developed within this project and the finalising of outputs and the submission of this work is now the top priority. Of course, the EQC support of this research will be appropriately acknowledged in these publications.
The specific list of publications include:

- Modal filtering methods for hysteresis based structural health monitoring
- Experimental validation of Hysteresis Loop Analysis (HLA) monitoring methods for bridge piers
- Mode filtering methods for multi-story SHM: An experimental validation study
- Fibre-model development for determination of reinforcement de-bonding lengths and correlation to SHM identification results.

It may still be some time before these papers undergo a full peer review process and responses to external reviewers are prepared. However, the supervisory team and the student fellow are committed to seeing this process through to completion, even though it will inevitably continue beyond the nominal end date of the project.

While the final outputs are yet to be published, the outcomes from this research are a notable extension to the pragmatic SHM methods developed within our research group at UC. Eimantas has undertaken some great research to date and the primary goal of the supervisory team is to now ensure that this work is appropriately disseminated through high quality journal publications. We feel that the research themes are strongly aligned with the EQC mission and that the research outcomes will be of benefit to the wider New Zealand (and international) earthquake research and practicing engineering community.

Thank you for your time and consideration of this report, and your support of this research. Please do not hesitate to contact us directly if you require further information or clarification.

Kind regards,

[Signatures]

Associate Professor Geoffrey Rodgers                   Distinguished Professor Geoff Chase
Bibliography: Eimantas Poskus:

Journal articles:

Conference articles:

Several other journal articles are in preparation and under review. This list will be updated as they are accepted and published.