BENCHMARKING THE SEISMIC PERFORMANCE OF MODERN NEW ZEALAND CONCRETE BUILDINGS

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Statement of the problem

In New Zealand and many other areas with high seismicity, the design of modern structures follows standards and guidelines that do not provide an explicit understanding of the building performance during earthquakes with different hazard levels. This shortcoming of current design standards has been observed after the Canterbury earthquake sequence of 2010 to 2011 that caused billions of dollars' worth of damage to the buildings of Christchurch and surrounding towns. Canterbury earthquake sequence also emphasized that earthquake damage to nonstructural components and contents poses a direct and indirect threat to the safety of people as well as loss of critical function and economy. However, until recently, the importance of nonstructural damage has not been appropriately investigated, and the engineering solutions required to prevent this type of damage has not been provided. In this context, a better understanding of the building performance in response to earthquakes with a various probability of occurrence is essential for the improvement of current design strategies and decision-making policies as well as development of the new policies which allow for increased resilience. Finally, in order to better influence the decision-making, building performance shall also be reported as the expected consequences in terms of direct economic losses and downtime.

The immediate need for investigating the seismic performance of modern New Zealand buildings has been seen through the UC Quake Centre's engagement with engineering practitioners. As an initial attempt, this project intends to benchmark the seismic performance of modern New Zealand concrete buildings following a robust seismic performance and loss assessment methodology. The benchmarking process provides a measure of the quality of the current design methods and decision-making strategies.

The main objectives of this benchmarking exercise are:

- To better understand the building performance considering the performance of both structural and nonstructural components
- To quantify the extent of damage to structural and nonstructural components after an earthquake event and attributed losses
- To determine if and where any improvements to the current design procedures are required
- To use this information to develop plans on how to make improvements in the building seismic performance

Research methodology

The methodology considered in this project is based on the Pacific Earthquake Engineering Research Center's (PEER's) framework for Performance-Based Earthquake Engineering (PBEE) methodology. Elements of the process include seismic hazard analysis, structural analysis resulting in quantification of engineering demands, damage analysis and identification of damage to the building components and contents, and loss analysis. PEER's framework provides a comprehensive understanding of risk exposures related to structural and nonstructural components and contents and facilitates decision-making for territorial authorities, property owners, commercial tenants, engineers, and contractors. Figure 1 illustrates the fundamental steps considered in the PEER's framework.

Benchmarking the seismic performance of buildings is meaningful only if a broad range of design and detailing configurations are considered. In this matter, a design space including numerous archetype designs is intended to be developed to consider various structural configuration issues and seismic behavioral effects. This design space is, consequently, assessed through the PEER's framework.

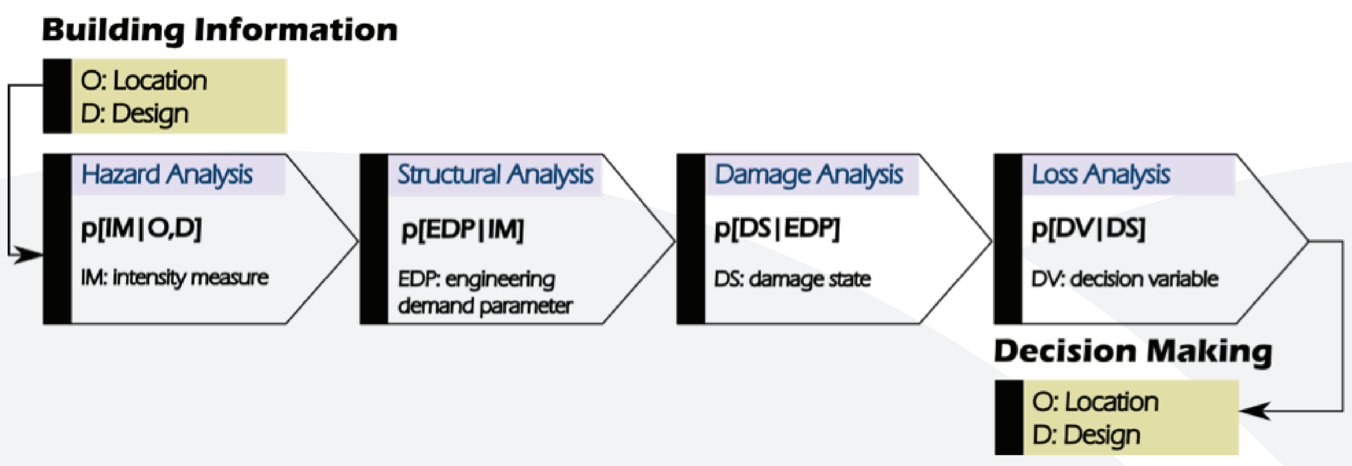

Figure 1. PEER's framework for performance-based earthquake engineering.

Project outcomes and deliverables

Development of a Seismic Loss Assessment Tool (OpenSLAT)

As part of this project, a computation tool (OpenSLAT) is being developed at the UC Quake Centre to facilitate the process of seismic loss assessment. OpenSLAT can be used to quantify the likelihood of damage that can occur to the components of the building and how long it will take and how much it will cost to repair. In other words, OpenSLAT is a useful tool to measure how much seismic activity will cost a building owner over the life of a building.

OpenSLAT will have a graphical user interface (GUI) to provide simplicity in use and allow broad uptake of the tool. In addition, it is envisaged that the source-code for the 'engine' of OpenSLAT is remained open-source as this allows researchers to continue to contribute to it.

Robust presentation of seismic performance of modern concrete buildings

The statistics of the structural analysis performed can be used as a rigorous mean to investigate the main objectives of seismic performance benchmarking including:

- Quantification of the response of modern buildings at various hazard levels
- Development of hazard curves for various engineering demand parameters
- Evaluation of collapse fragility including probability distribution of collapse, median collapse intensity, and associated dispersion
- Computation of collapse margin ratio (CMR) defined as the ratio between the median collapse capacity and the maximum considered earthquake intensity
- Calculation of annual rate of collapse representing an effective metric for assessing collapse safety

Consideration of this robust seismic performance assessment over the developed design space (i.e. a set of various designs) can, in turn, results in:

- Assessment of the adequacy of current design assumptions and detailing configurations
- Comparison of the performance of modern buildings considering variation in the critical design assumptions

An example demonstration of the results prepared for a ten storey concrete frame building designed for Christchurch (know as New Zealand Redbook building) is shown in Figure 3

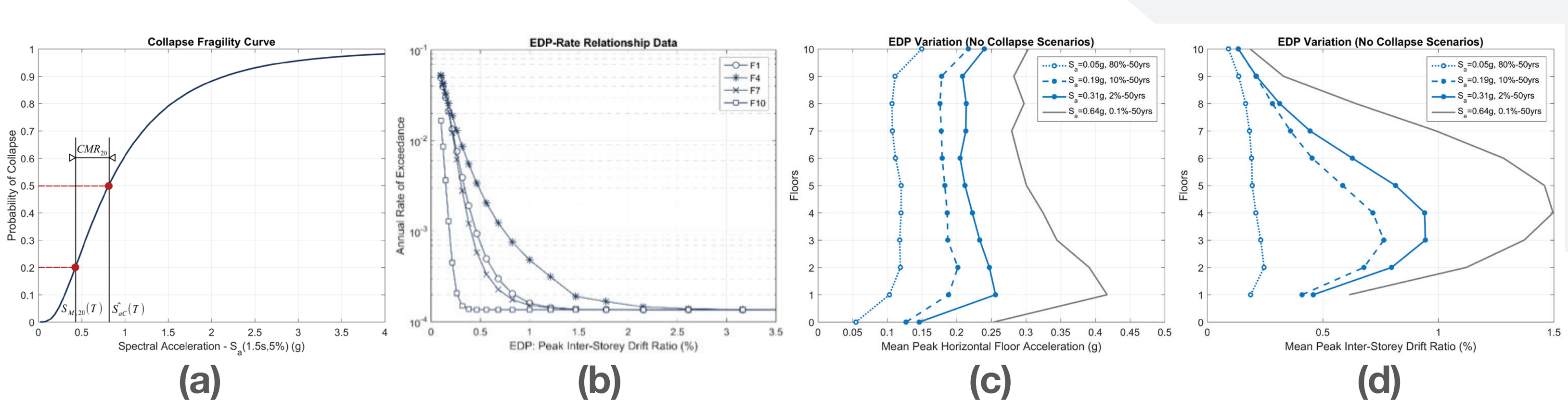

Figure 3. Illustration of (a) mean peak inter-storey drift ratio, (b) mean peak floor acceleration, (c) hazard curve for peak inter-storey drift ratio, and (d) collapse fragility.

Presentation of direct economic losses and downtime associated with modern concrete buildings

An appropriate benchmarking of seismic performance of a building also requires a quantifiable relationship between the seismic hazard and the expected economic loss in a building. In this matter, quantification of the following losses are insightful for decision-making process:

- Loss-intensity relationship for entire structure considering global structural collapse and non-collapse cases
- Disaggregation of non-collapse loss by building components
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- Net present value of the expected loss over time

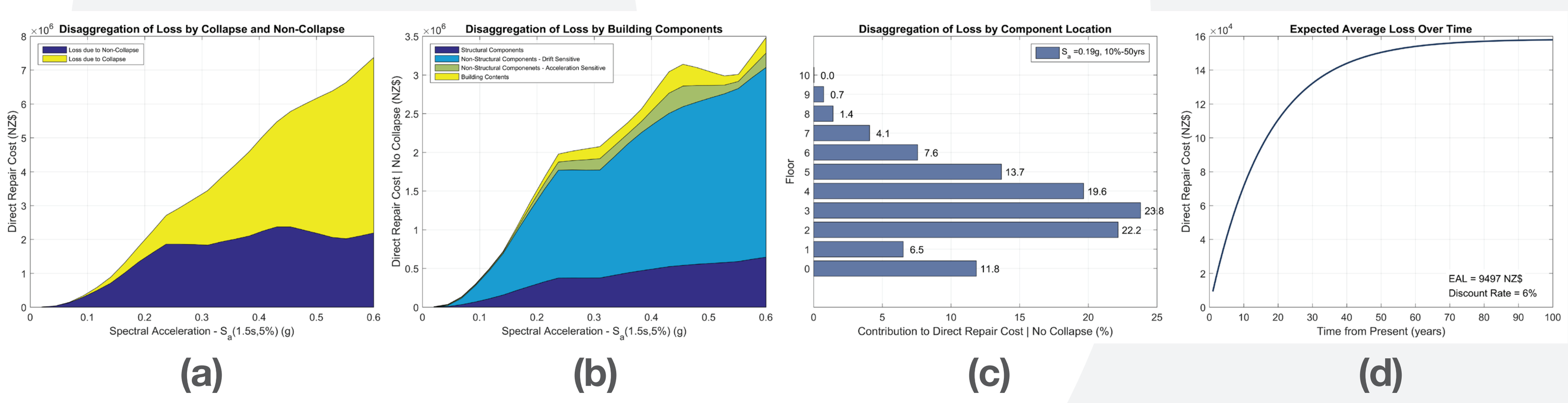

Figure 2. Illustration of (a) loss-intensity relationship, (b-c) loss disaggregation, and (d) expected loss over time.

Impact of the output in New Zealand industry

Major benefits from conducting this research can be summarized as:

- Establishment of a robust framework to be used for investigating the seismic performance of New Zealand buildings which are existing or to be designed based on modern design standards or new damage-controlled technologies.
- Development of an enhanced basis for decision making in regards to whether further efforts to be considered for improvement of the current design standards.
- Quantification of the risk associated with poor building fit-out within the New Zealand building stock.
- Development of a robust framework to investigate how significantly the overall system performance can be improved by using improved nonstructural systems
- Provision of a seismic loss assessment tool for consultants to make improved design and retrofit decisions

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