Structural Resilience and Functionality Implications of Designing to Various International Standards

Nikki BUCK | Georgi CLARKE | Max STEPHENS | Lucas HOGAN
The University of Auckland | nbuc77@aucklanduni.ac.nz

OBJECTIVE

This research compares the seismic performance of reinforced concrete buildings designed to various international codes in terms of economic loss and functionality as a way to improve the resilience of structures designed in New Zealand.

APPROACH

The framework is developed through the design and assessment of four 10-story concrete moment frame buildings designed using New Zealand material properties and seismic hazards but with design procedures and detailing requirements based on New Zealand, United States, Japanese, and Chilean standards, respectively.

01 | CASE STUDY BUILDING

A reinforced concrete (RC) moment frame building designed to Japanese standards was selected as the case study building. The structure is a full scale 10-story building tested at the E-Defense shake table facility in Japan in 2018.

The structure has plan dimensions of 12m x 8m and is 25.75m tall. The lateral force resisting system consists of two 3-bay perimeter moment frames in the longitudinal (y) direction.

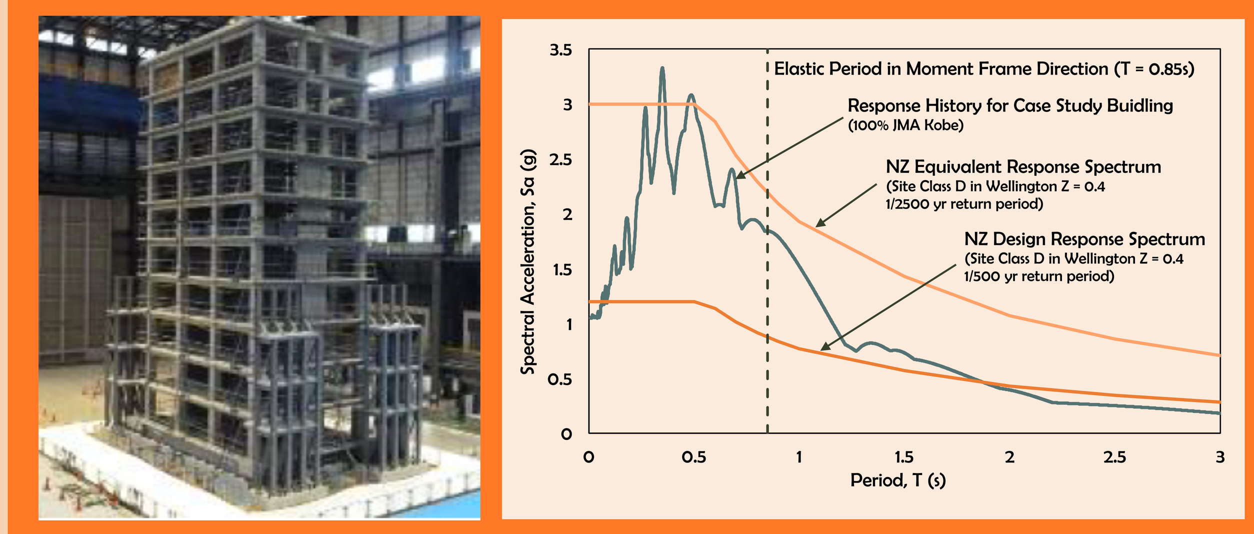
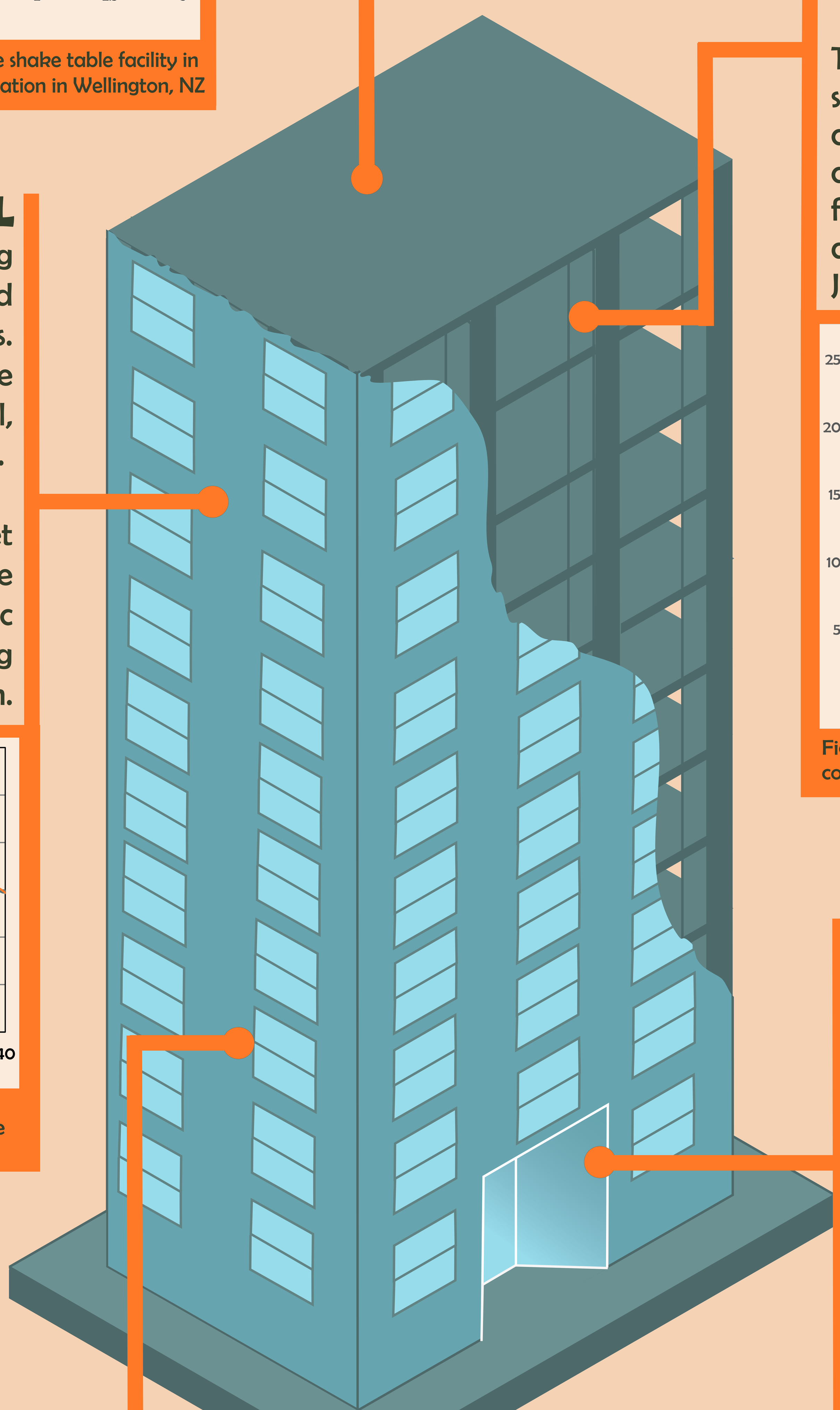


Figure 1: (a) 10-story RC moment frame building tested at the E-Defense shake table facility in Japan (Sato et al., 2017) and (b) Equivalent Demands for a structure location in Wellington, NZ



02 | MOMENT FRAME DESIGN

The case building is re-designed in the moment frame direction following New Zealand, United States, Japanese, and Chilean standards with columns designed as rectangular and beams designed as "T" sections.

The moment frames are designed for the demands on a structure located in Wellington, NZ (Z=0.4) with site class D soil conditions. All designs use New Zealand material properties for concrete and steel reinforcement. Larger design demands and a focus on limiting drift can result in buildings that are more elastic and have larger beams and columns; as is typically the case with Japanese and Chilean moment frame buildings.

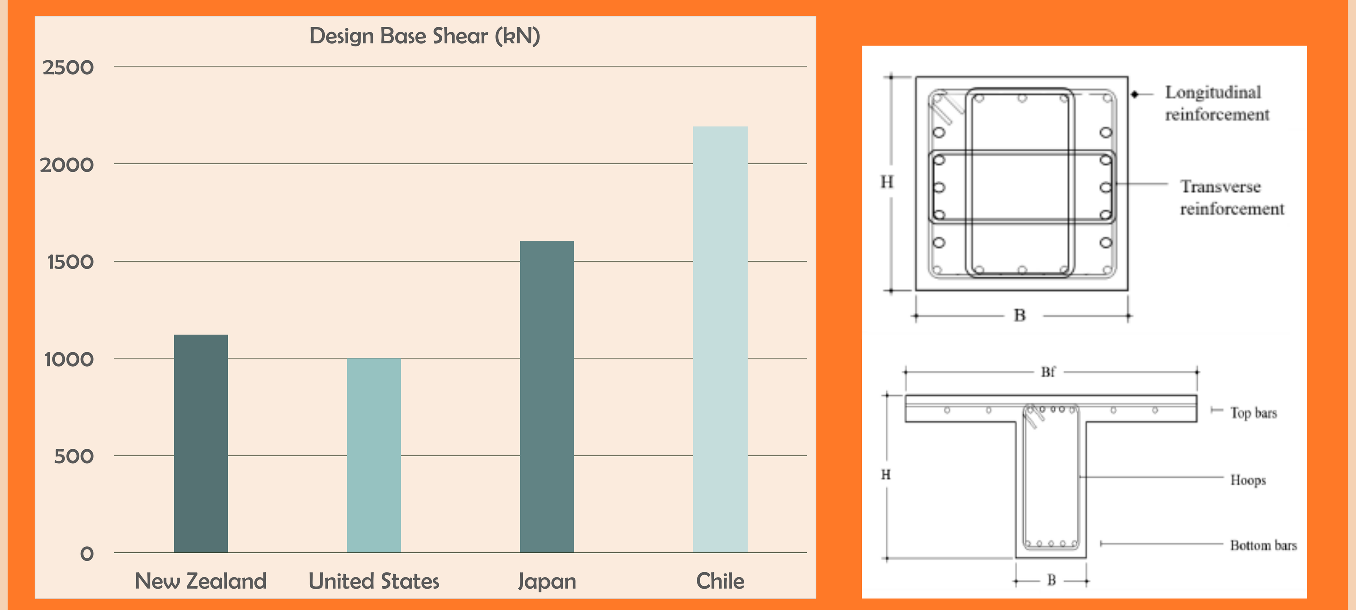


Figure 2: (a) Comparison of design base shears for each moment frame design and (b) Typical column and beam cross-section design

03 | NONLINEAR MODEL

A nonlinear 2D model of the case study building moment frame was created in OpenSeespy and validated with results from E-Defense shake table tests. The beams and columns of the moment frame are modelled with fibre sections combining steel, unconfined, and confined concrete materials.

Beam-column joints are modelled with rigid end offset lengths based on beam to column strength ratios. The nonlinear model will be used to conduct a probabilistic structural response assessment (PSRA) for each building design considering a range of hazards for Wellington.

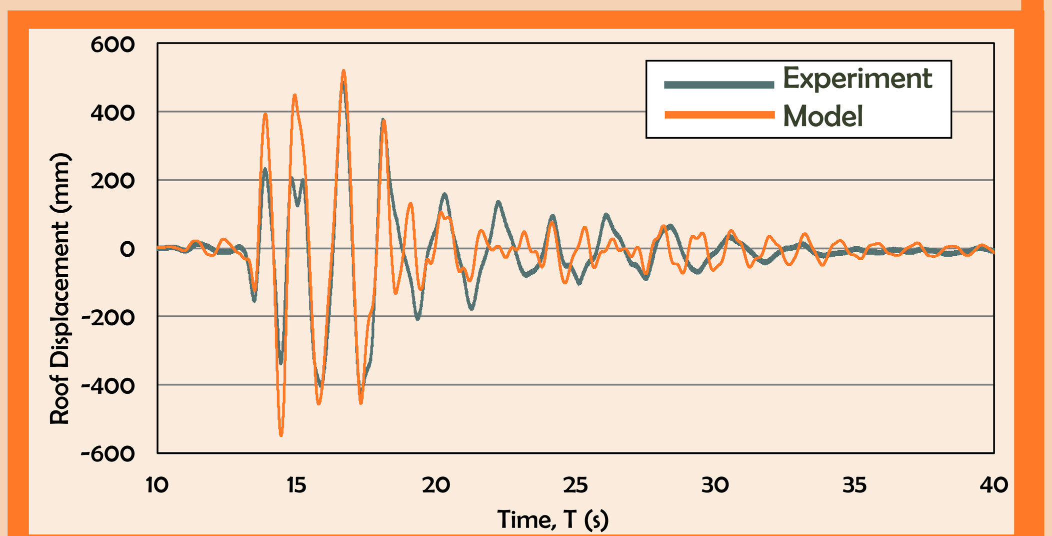


Figure 3: Roof displacement history results of nonlinear structral model compared to results from E-Defense shake table tests with 100% JMA Kobe earthquake shaking

04 | LIFE CYCLE COST EVALUATION

Results from the PSRA will be used to conduct post-earthquake loss assessments for each building design using the FEMA P-58 Performance Assessment Calculation Tool (PACT) to provide estimates for annual losses in terms of repair cost. PACT uses a fragility-based approach to estimate damage to structural and non-structural components.

The life cycle cost for each design will be calculated as the total construction cost plus any additional repair costs.

05 | RISK-BASED FUNCTIONALITY ASSESSMENT

Finally, a risk-targeted approach will be used to assess the post-earthquake functionality level of each building design. An initial framework has been developed that provides a scaled functionality risk of each non-structural component in terms of building safety, building access, and tenant function.

These results will be compared to the results from the loss assessments and the framework will be adjusted based on non-structural components that had that greatest impact on the lifecycle cost of the building.

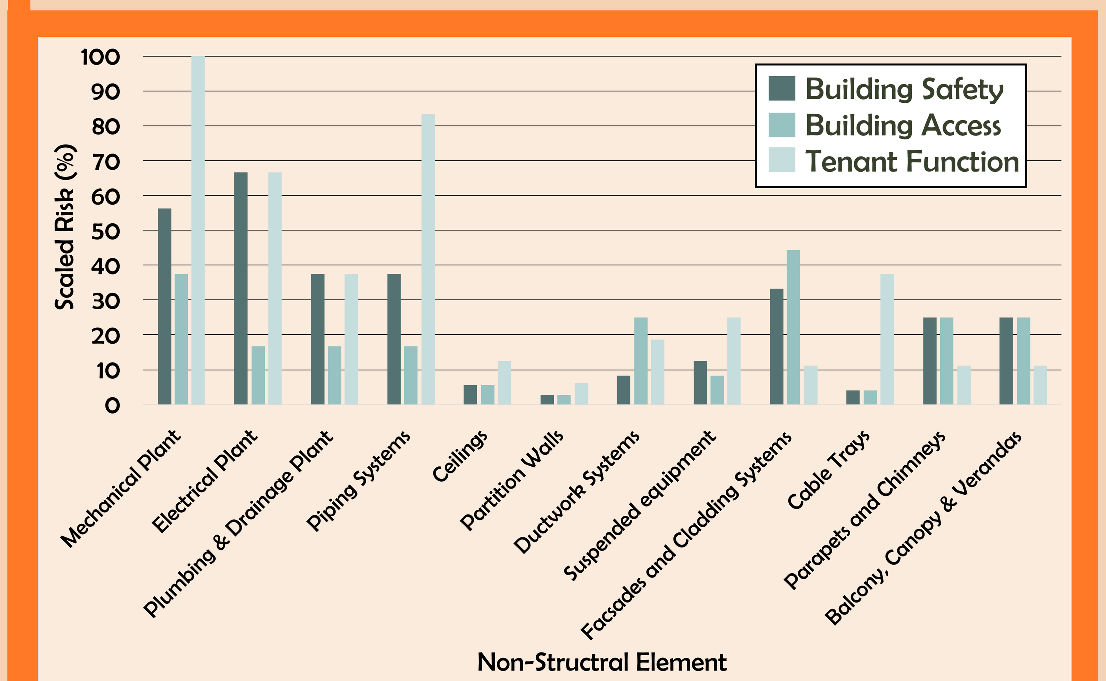


Figure 4: Proposed functionality framework output for an IL2, flexible moment frame with comprehensive seismic protection and normal occupany type building (Clarke)

EXPECTED RESULTS & FUTURE WORK

The building functionality of each design will be quanitifed using the proposed risk-based approach that relates component-level damage to building-level function. Results from the loss assessment will be used to update the functionality assessment framework by indentifing which non-structural components are most likely to impact building functionality based on their sensitivty to damage. The results from the loss and functionality assessment will be used to provide recommendations for potential design strategies currently used in other countries that would improve the resilience of concrete structures in New Zealand.

REFERENCES
Sato, E., Tosauchi, Y., Fukuyama, K., Inoue, T., Kajiwara, K., Shiohara, H., . . . Mukai, T. (2017). 2015 Three-dimensional Shaking Table Test of a 10-story Reinforced Concrete Building on the E-Defense: Part 2. 16th World Conference on Earthquake Engineering, 16WCEE. Santiago, Chile.

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