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Early Results from a Methodology to Leverage Seismic Risk Assessments to Inform Seismic Policy Development in the City of Vancouver

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ABSTRACT

Vancouver, British Columbia is located in one of Canada's most active seismic regions. Because most of the seismic risk in the city's 90,000 existing buildings has not been addressed, due to a lack of robust retroactive upgrade requirements, Vancouver's government has embarked on a multi-year policy option development process. This work builds on an emerging methodology proposed at the 12th National Conference on Earthquake Engineering in 2022, an approach that is aimed at bridging the present gap between knowledge, generated through seismic risk assessment, and seismic risk reduction action. Specifically, this work provides early findings from implementing this methodology, using Vancouver as an in-process case study. The methodology, intended for use by government planners, is rooted in the idea that achieving broad consensus and substantive action must begin with a quantitative account of risk. It pushes risk data beyond simple narrative, considering how seismic risk modelling outputs can be leveraged to develop risk reduction policy options. This methodology considers risk in terms of four metrics: severe injuries and casualties, heavy building damage, long-term disrupted occupants, and direct financial losses. It begins by generating a set of risk metric-ranked groupings of buildings translating seismic risk outputs into a set of policy-actionable risk-driving cohorts. These cohorts are then modelled in terms of risk reduction potential, supporting policy option analysis by planners. Parsing risk and modelling risk reduction potential supports priority-making, policy development, and ultimately decision-making while promoting robust public, stakeholder, and political communication. In effect, the methodology not only reveals risk but generates an actionable understanding risk allowing municipal staff and decision makers to make highly informed policy decisions, including risk reduction targets and seismic risk reduction policies.

Keywords: Regional Seismic Risk Modelling, Earthquake Mitigation, Policy Development, Retrofit Schemes

INTRODUCTION

This work builds on a 2022 methodological approach, namely *A Methodology to Leverage Seismic Risk Assessments to Inform Seismic Policy Development, the Case of the City of Vancouver* [1], developed in an attempt to implement the core goal of the United Nations Sendai Framework for Disaster Risk Reduction 2015-2030 [2]: to understand and ultimately reduce community disaster risk. The Sendai Framework makes explicit that quantitative assessment as well as an objective description of local risk is a key first step for communities to reduce risk from disasters more effectively and efficiently. Aligned with these objectives, the City of Vancouver (hereinafter referred to as the City), British Columbia is currently in the process of developing seismic risk reduction policy options as a part of its implementation of the City's 2019 Resilient Vancouver Strategy [3]. Vancouver is located in one of the most seismically active regions in Canada, susceptible to seismicity from the Cascadia Subduction Zone, deep intraslab events, and rare but highly consequential shallow crustal earthquakes. The methodology at the core of this work, as well as the early results presented herein, use Vancouver's stock of 90,000 privately held, existing buildings as an in-progress case study to inform the development of seismic policy. More specifically, this study examines how to leverage the quantitative outputs of a regional seismic risk assessment to aide in a municipality's work to both understand and ultimately reduce its earthquake-induced building risk.

This methodological research emerged through an ongoing partnership between the City, the Geological Survey of Canada (GSC), the Province of BC, and the University of British Columbia (UBC). To start, knowing that Vancouver and BC lack robust retroactive upgrade requirements [4], the City completed a comprehensive seismic risk assessment in partnership with GSC using the Global Earthquake Model's OpenQuake platform [5]. This assessment serves as a foundational element to not only Vancouver's seismic risk reduction work, but also the core of this methodological research and its results.

This ultimate risk reduction aim of this methodology is to guide decision makers, planners, and stakeholders in the development and prioritisation of risk reduction policy options. These options – critically informed by and paired with policy considerations such as building replacement and upgrade cost, occupant impacts, climate mitigation and adaptation, housing affordability, and equity – will ultimately ground the socio-political process of arriving at consensus policy solutions to reducing seismic risk. This methodology also relies upon and assumes a pre-existing political mandate to prioritise and engage in this work. The following sections will review the development of Vancouver's seismic risk model, the methodology, and early results from testing the methodology.

REVIEW OF MODELLING SEISMIC RISK IN THE CITY OF VANCOUVER

Seismic risk modelling uses generalised building typologies [6] with fragility and vulnerability functions [7] that describe the probability of experiencing different damage extents and loss ratios as a function of relevant ground motion intensity measures. These models generate damage and loss results for each building, which can be translated into additional metrics (e.g., casualties) using consequence models such as those in HAZUS [8]. This work leverages the principal definition of seismic risk modelling, which quantifies risk as a product of exposure, hazard, and vulnerability, to identify the building cohorts that concentrate Vancouver's citywide seismic risk.

Vancouver's seismic risk assessment utilised a surveyed parcel-scale building inventory, where data was collected using several windshield surveys, virtual windshield surveys (i.e., Google Streetview), site visits, and plan reviews. The development of this inventory was a detailed and involved process, but the resulting spatial account of Vancouver's buildings allows for more detailed analysis. In terms of seismic hazard, Vancouver is exposed to potential earthquakes of significant magnitude and a range of seismic sources, with ground motion shaking potentially amplified by the presence of the Georgia sedimentary basin [9]. This work leverages a set of deterministic scenarios, informed by Canada's sixth generation national seismic hazard model (CanadaSHM6) [10]. In particular, this paper focus on the results of a Georgia Straight M7.2 shallow crustal event. The use of deterministic scenarios like the Georgia Straight event is preferred by cities for policy planning as it allows decision makers to understand the potential for risk reduction and make informed policy decisions.

The generalised building typologies used in the seismic risk assessment are grouped by occupancy, material, structural system, and construction design level [11] with fragility and vulnerability functions [12] that describe the probability of experiencing different damage extents and loss ratios as a function of spectral accelerations for relevant periods. GEM worked in partnership with NRCAN to develop Canada-specific fragility data conducive for seismic risk analysis. The original HAZUS capacity curves were modified to reflect Canadian construction practice and used to inform the development of simplified nonlinear structural analysis models. Non-linear response history analysis results were used to develop the corresponding fragility and vulnerability functions [13]. These functions express the probability of observing different damage states (i.e., slight, moderate, extensive, and complete) as a function of spectral acceleration at periods of 0.3s, 0.6s and 1s for low, mid-rise and high-rise buildings. While this works uses the most presently available fragility data available in Canada, we recognize its limitations in capturing the seismic response of tall buildings, with complex dynamic behaviour and fundamental periods of vibration well in excess of 1s [14].

BRIEF METHODOLOGY OVERVIEW

The three stages of this methodology, illustrated in Figure 1, function iteratively to advance the analysis and political actions necessary to spur seismic risk reduction policy: (1) the risk assessment, described above, (2) the policy analysis and development process, described next, and (3) the political process. This methodology assumes broad political will, and while it does not propose forms of public communication, those elements are critical to establish and maintain an ongoing mandate for this challenging work. The political process, visualised in the context of this methodology below, is often the first step and must be paired with process-long stakeholder engagement. Local context, above all, drives interpretation of risk modelling outputs and must drive policy development.

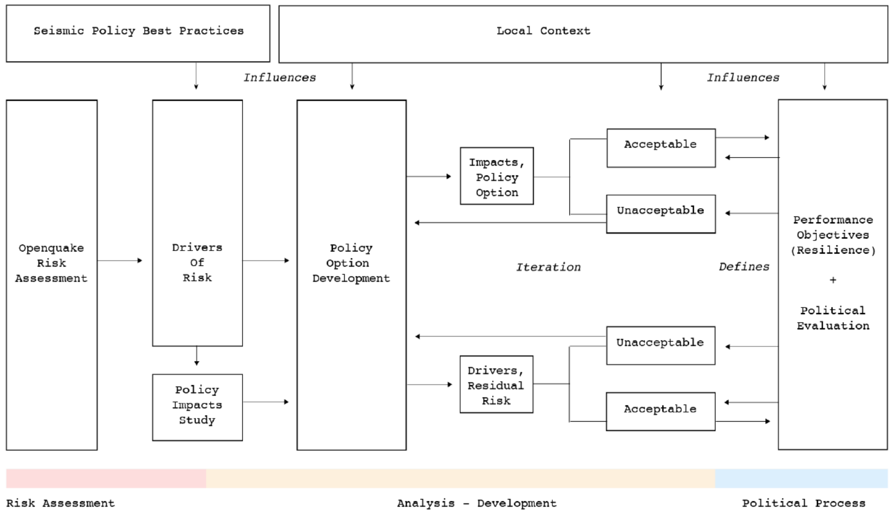

Figure 1. Seismic policy development framework.

The policy analysis and development process – the core of this methodology – begins through the generation of a set prioritised grouping of buildings, selected based on their contribution to pre-defined risk metrics, selected to translate complex regional seismic risk information (i.e., OpenQuake outputs) into a set of policy-actionable risk-driving cohorts. Critically, these cohorts then become the objects of policy option generation and the modelling of risk reduction potential during the policy development process. Specifically, this methodology proposes utilizing OpenQuake to model the risk reduction potential of upgrading each cohort as part of the policy development process and the political evaluation (See Figure 1) of policy option outcomes (i.e., acceptable or unacceptable). This risk reduction modelling is in addition to the baseline risk modelling that serves as the foundational data of the policy analysis and development process. The risk reduction modelling relies on a determination made between local engineers and risk modellers, considering what design level increase (e.g., from pre-code to moderate code) is appropriate for different building types based on what can be reasonably achievable via retrofit interventions.

Parsing cohorts from the massive amounts of tabular data output from risk modelling is done by assessing the risk metric contribution of various building typological configurations, considering building HAZUS structural typology [15] in combination with occupancy type and design level (based on construction year). These cohorts of buildings are the prioritized based on their contribution to citywide risk, as seen in Figure 2, in terms of extensive and completely damage buildings, loss of life and severe injury, occupant disruption/displacement for 90 or more days, and direct financial losses. In terms of prioritization, cohorts that drive citywide risk across multiple metrics are prioritized above those that contribute far less. Some cohorts that contribute very little (or represent a small proportion of the building stock) are considered residual risk. As seen in Figure 1, residual risk is assessed alongside the risk reduction potential of policy options within the political process. This provides a comprehensive view of both risk and risk reduction.

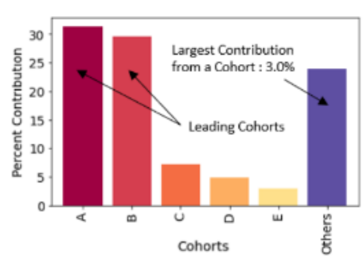

Figure 2. Example of cohort prioritization illustrating the percent contribution of different cohorts to a pre-defined risk metric.

The process of policy development, where seismic risk assessment outputs are linked to policy option development through the modelling of prioritized cohorts for risk reduction potential, focuses on the development of policy option sets. These sets consider a set of building upgrades (that can be modelled) occurring to various cohorts over time. The modelled risk reduction output of these sets can be assessed, in terms of both cohort focus and time, in concert with other policies and policy considerations by decision makers and planners alike. This allows risk reduction potential to meet the various considerations, challenges, and goals that planners and decision makers consider when determining any potential policy, with additional considerations beyond seismic risk.

RESULTS OF CASE STUDY TESTING - VANCOUVER

Early results from the implementation of this model using Vancouver's ongoing risk assessment outputs allow us to see how this methodology works to provide critical information to planners and decision makers. Figure 3 below shows some these early results, where prioritized cohorts labelled A-1, etc. are placed into a policy option set. For the purposes of this test policy option set, representative timeframes were developed based on other municipalities' seismic risk reduction programs [16, 17]. We see below how A-1's retrofit substantially reduces the number of extensively and completely damaged buildings as well as the number of people severely injured or killed citywide. This reduction occurs by year five of the model policy option set's overall timeline.

In terms of translating these findings into policy development and decision making, these results are highly instructive. They allow policy makers to observe what the risk reduction benefit of policy action would be over time. This can be understood alongside other planning efforts. It is likely that the results below would be seen by a policy maker as entirely insufficient, so much so that examination of the sources of residual risk as well as the particulars of the seismic upgrades would likely be considered – to refine this policy option set. Planners can, using this methodology, approach planning for seismic risk reduction iteratively using highly refined data to nimbly make intricate changes to policy option sets in response to any number of potential municipal scale – equity, affordability, climate action, retrofit feasibility, market capacity, etc.

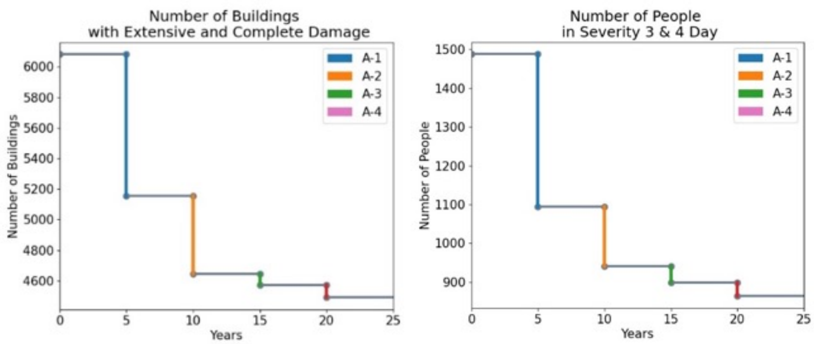

Figure 3. Implementation of prioritized cohorts (grouped from A-1 to A-4) showing risk reduction grouping contribution on an assumed risk reduction policy set over time.

In future implementations of this methodology, it is possible to look at the replacement of some buildings, reflecting land use changes (e.g., densification, redevelopment, etc.) over time or considering the potential of simply replacing some at-risk buildings. When growth-based change is expected and land use patterns fluctuate over time, a more nuanced landscape of seismic risk and risk reduction (i.e., modelling policy option sets) can be seen.

CONCLUSIONS

This work sets out one methodology for leveraging seismic risk assessment as a critical decision-making tool in seismic risk reduction planning and policy work. Creating meaningful links between the risk assessment outputs and the sets of plans, policies, challenges, and discourses present in municipal planning is an essential and foundational element of implementing meaningful and lasting seismic risk reduction action, particularly by expressing the benefits (as well as limitations) of building seismic upgrades at a citywide scale. This methodology provides planners with a clear pathway to move from extensive risk assessment tabular data to legible risk-driving cohorts, narrowing the focus of policy and setting up potential risk reducing policy options. Planners and decision makers can take a surgical approach to policy planning to maximize seismic risk reduction, rather than relying on risk reduction policy best practices or other more general understandings of seismic risk and risk reduction options.

While this methodology offers a clear pathway for planners, the process requires a good deal of interface between risk modellers, the local engineering community, and planners. This need for a planner proficient in seismic risk modelling, or with ongoing access to a consulting engineer and risk modeller, may not be feasible for some municipalities. While complex, this work shows a methodology that empowers planners with a clear path to leverage seismic risk modelling in seismic risk reduction planning.

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