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T.E. Hobbs[1,2], J.M. Journeay[1], and P. LeSueur[1]

[1]Geological Survey of Canada, 1500-605 Robson Street, Vancouver, British Columbia
[2]Department of Earth, Ocean, and Atmospheric Sciences, University of British Columbia, 2020-2207 Main Mall, Vancouver, British Columbia

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Abstract

The first published Canadian Seismic Risk Model, CanSRM1, is set for release this year. It considers the potential impact of seismicity on Canadian building stock and people, taking into account the current built environment. To understand the benefits of retrofit policies, policy makers need a base of evidence showing the difference in risk before and after retrofitting. Therefore, we plan to incorporate a simulated retrofit scenario into the national model, after consulting with practicing engineers and experts to better understand how such retrofits are likely to occur. This report presents the outcome of that consultation process, and recommendations for implementation into CanSRM1. It is apparent that only modest retrofits should be simulated for the majority of buildings, except those which are expected to serve a post-disaster function. Other building types are poorly suited for cost-effective retrofit, such as unreinforced masonry. These ideas are used to create a retrofit scenario across Canada, which can be used by policy makers to create targeted seismic risk reduction policies.

1. Introduction

The Canadian Seismic Risk Model, being completed by Natural Resources Canada (NRCan), is a comprehensive neighborhood-level risk assessment for the country. The model involves consideration of risk both to baseline building stock and the same building stock under simulated retrofitted conditions. The technical specifics of this work are generally described elsewhere and based on models and software which have been independently developed, reviewed, and published (e.g. Pagani et al., 2014; Silva et al., 2014; Hobbs et al., 2021a; Hobbs et al, 2021b; Journeay et al., 2022). However, the retrofit schema was developed specifically for use in the national model based upon consultation with the engineering community. The consultation process and finalized schema are described herein.

2. Motivation

NRCan's exposure database (Journeay et al., 2021) is a representative national inventory, matching census information to patterns of human settlement observed from space. It includes, among other things, information about a building's construction material, primary force-resisting system, period of construction, seismic design level, and primary occupancy type. These conditions makeup the baseline for risk assessment.

To aid decision makers in evaluating the benefit of different mitigation measures, the risk model also considers the same building inventory under retrofitted conditions. These conditions are envisioned as matching the most common or most practical type of retrofit, expressed as a change in the design level of a building. For example, retrofit of a low-code building could be simulated by mapping that building to moderate- or high-code. Results for these simulated conditions are calculated for all buildings, such that the results of the retrofitted and baseline conditions can be selectively combined to consider the retrofit of targeted portfolios of buildings. For example, results from the baseline condition could be compared against the results if all pre-code, high-rise concrete buildings were retrofitted. Or perhaps only such buildings that exist along so-called emergency disaster routes would be considered.

It is understood that this approach is best suited to consideration of a large portfolio of buildings, and that it should not be used for consideration of individual buildings, due to the generalized nature of the building taxonomies, the generality of the retrofit proxy, and any local considerations that would apply in the development of actual existing building mitigation strategies. However, the methodology represents a novel ability to consider the large-scale impact of potential retrofit measures without any demand on the user to conduct site visits, hold a site-level inventory, or have any in-depth engineering knowledge. These features make it incredibly valuable as a high-level screening tool for upcoming existing building codes, or for the development of municipal retrofit guidelines.

3. Methodology

There are four existing levels of seismic design code in Journeay et al., 2021: pre-code (PC), low-code (LC), moderate-code (MC), and high-code (HC). The original retrofit methodology involved mapping buildings to two increased levels of seismic design, creating so-called r1 and r2 retrofit scenarios. For example, a pre-code wood frame home (RES1-W1-PC) would be mapped to one and two levels higher: RES1-W1-LC and RES-W1-MC under r1 and r2, respectively. However, it was found that invoking two levels of retrofit was cumbersome for keeping track of results and there was insufficient demand for that level of detail. Accordingly, under informal consultation with local practitioners, NRCan developed a single set of retrofit conditions.

As part of the peer review process for the Canadian Seismic Risk Model, NRCan contracted Dr. Tuna Onur of Onur Seemann Consulting, Inc. to examine the methodology employed. The single retrofit scheme that was developed after these consultations and feedback from Dr. Onur was based upon the principles that (1) mid- and high-rise buildings tend to be expensive and/or impractical to retrofit up to a high design standard and thus can only be retrofitted by one level; (2) taxonomies with unreinforced masonry structural elements, including C3, S5, and URM, cannot be retrofitted to a mid- or high-code level of performance – a so-called low-code threshold; and (3) precast concrete is uncommon to retrofit and thus can only be retrofitted by one level.

The resulting scheme, Figure 1, was then sent to a number of local engineering firms for review. Firms were selected as those who were active in British Columbia's ongoing School Seismic Retrofit. Their feedback was welcomed either as comments on the specific elements of the scheme or on the approach in general. Below, the raw feedback is documented with the name and contact information of the associated reviewer. Afterward a summary is provided including recommended actions.

4. Responses

The goal of this work was to ensure that the retrofit scheme enacted is generally in line with current and common retrofits that would most closely mimic the kinds of alterations that might be mandated under a municipal retrofit policy. We sought feedback from 11 people at 4 engineering firms, 1 university, and 1 municipality. These institutions were selected as those who are currently actively engaged in the design, implementation, research, or policy elements of retrofits. We received 7 responses from 5 organizations, surpassing our goal of 3 independent reviews. This document was then circulated back to the respondents for review and confirmation that their views were portrayed correctly.

Response 1 – Email from Timothy White, Ph.D., P.Eng., Partner at Bush Bohlman & Partners (February 23, 2021)

Very interesting initiative. Here are comments based on my experience (mostly with schools, hospitals and civic buildings):

1. Seismic retrofits are rare. Owners needing to renovate or expand their building will often choose the route that avoids a seismic upgrade because they are costly.
2. The level of retrofit is more dependent on the intended future use of the building than what code it was designed to initially.
3. For all public schools in BC, even those with URM, we upgrade to the SRG [Seismic Retrofit Guidelines]. This upgrade usually lands between 60-80% of current code – so would probably be approximated by the "moderate code" level.
4. URM can be upgraded considerably. It really depends on the type. Concrete masonry can be upgraded to a high code level without being overly onerous. If the masonry were clay brick, hollow clay tile or stone, yes I can see that being far more expensive. I don't actually see the point in just upgrading to a low code level – this barely protects the building – perhaps that is sufficient outside of BC. But in BC, you'd have trouble justifying such a low upgrade to the building authority.
5. I've upgraded two pre-cast buildings. One was for transportation which we did to the high code level and another we did to a moderate code level.
6. I've been part of 3 hospital upgrades. All the originals ranged from pre-code to moderate code, but in all cases we upgraded them to high code.
7. For our civic buildings it really depended on the level of upgrade the municipality wanted. We upgraded part of a fire hall to moderate code and a city hall to high code. I think in both cases the existing building would either have been low or pre-code.

So I guess my recommendation would be to assume that, at least in BC, any upgraded structure be done to at least moderate – and if it is a structure that would need to function after an earthquake, assume it would be upgraded to high code.

I think also it really is funding dependent. Hospitals and civic buildings tend to be on an individual basis. Schools are being upgraded to moderate as they are part of a province wide program. But not all the schools have been retrofitted, even after 15 years. There are 188 completed but still over 350 high risk schools.

Regards,

Tim White, Ph.D., P.Eng.

Response 2 – Email from Andy Metten, P.Eng., Struct.Eng., Partner and Structural Engineer at Bush Bohlman & Partners (February 28, 2021)

A couple of comments:

1. Just wondering if it would not be better to use the seismic risk categories of NBC – however these include an importance factor and site factor.
2. It is difficult to see what you are really looking at – are you looking at risk with and without a retrofit? In terms of the total building stock very few have been upgraded for seismic.
3. In our experience – with the possible exception of schools - upgrades for seismic usually only happen when doing something else with the building – seldom as a stand[-]alone exercise.

4. Not sure the classification of "commercial" for buildings like hospitals. Suggest there should be an institutional with classifications for Post Disaster and for High Importance (schools, community centers).
5. Medical clinics are generally found in most office buildings, mini-malls and occasionally but not often as stand[-]alone buildings with only doctor's offices – not sure why these are being separated out from other similar uses. For example[,] would our building (1500 W. Georgia) which has a couple of doctors and mostly not be classified as medical clinic? How about Airport Square on W73 where my dentist is (incidentally this is a very high risk building due to its precast concrete core construction)?
6. For construction type there are a lot of buildings that were built in Vancouver in the first half of the 1900's where a steel moment-ish frame is encased in concrete. (Eg. Hotel Vancouver, waterfront station) the lateral system is supposedly this frame but in reality is the unreinforced masonry infill walls.

Will be interested to see what your results are!

Andy Metten, P.Eng, Struct.Eng.

Response 3 – Email from John Sherstobitoff, P.Eng., Principal at Ausenco (March 4, 2021)

A few comments

1. Seismic Design Level tab
    a. "NBC Site Seismic Category" (SSC) with six categories SSC-0 to SSC-5; I assume you're aware of new NBC 2020 Seismic Categories SC1 thru SC4. Worth noting or comparing? Confusing? Or have you considered this, and this is dealt with elsewhere?
2. Construction Type tab
    a. I provided my comments to Carlos Ventura recently on typology for the BC Housing initiative. Is this table consistent with that used/proposed by BC Housing per latest update by Carlos? Would be great if they were consistent.

Otherwise, all looks very reasonable ! [sic]

Regards, John

Response 4 – Notes from call with Carlos Molina Hutt, Ph.D., PEng., Assistant Professor of Civil Engineering at the University of British Columbia (March 9, 2021)

- Two levels of increased design is a rare occurrence, and it wouldn't occur as part of a municipal retrofit strategy. More likely you would introduce a one level increase and a few people might choose to increase by two. Existing programs like San Francisco's soft storey retrofit (https://www.structuremag.org/?p=14310) would be an example of a smaller intervention that's more consistent with one level.
- Example of a building that experienced a retrofit consistent with a two level increase: https://www.structuremag.org/?p=8333 and https://www.tippingstructural.com/projects/project_details/37#

- In agreement with performance-based interventions for high-importance buildings. Schools, hospitals are likely to be retrofitted to moderate/high, but general commercial buildings wouldn't get retrofitted to that high level unless a few owners decide to invest heavily.
- General retrofits would focus on life-safety.
- It would be important to include language in guidelines to help practitioners use this for realistic policy interventions. For example: retrofit selections of a particular taxonomy, not all buildings everywhere.
- Also[,] good to include in guidelines that of course each building is different and actual retrofit designs will vary even within a single taxonomy.
- The URM LC threshold is acceptable. Could think about other strategies, but this approach is good in that it emphasizes the limited realistic opportunities to significantly improve performance.
- It would be a necessary and helpful future step to obtain fragility functions for retrofitted versions of these taxonomies. The current approach can start the conversation but it would be important to build a more robust approach.

Response 5 – Notes from Micah Hilt, Lead Seismic Policy Planner for the City of Vancouver (March 9, 2021)

My comments are in line with those of Carlos Molina Hutt. Extensive high-level two design level retrofitting is an unlikely policy goal and is infeasible for many buildings and building owners – It should therefore not be modelled here. I suggest using only a one design level bump to model retrofitting, except URMs which should be capped at LC.

Buildings that are high code (and maybe even MC?) are unlikely to receive policy attention and therefore retrofits. It is important to see in modelling that those buildings will receive some damage (potentially heavy, if at or near a code-level shake), as the public generally believe new buildings to be some level of 'earthquake proof.'

Achieving a high code through retrofit is unlikely in most cases. Building improvement is generally along the lines to achieving a state that is comparable to a certain percentage of current code, so it would be hard to imagine a retrofit associated with policy-required or voluntary retrofitting that would hit 100% of any recent code.

An approach to this could be selecting to single DL [Design Level] bump only certain sets of buildings, such as known or modelling poor performers for a given set of exposed buildings.

Response 6 – Notes from call with Tuna Onur, Ph.D., P.Eng., Principal at Onur Seemann Consulting, Inc. (March 10, 2021)

- NBCC Commentary L is for existing buildings. Prior to 2015, it stated that if a building does not meet 60% of current code you must retrofit to 100%. As a loophole, it was possible to voluntarily retrofit to 70% prior to substantial alteration so as to not trigger the 100% mandate.

The commentary is not mandatory anyways, so there's interest in making an existing building code to enforce this.

- Generally[,] no one is going to retrofit above ~70% code (MC) unless it's a high importance building. If you're already MC and not an important building (hospital, etc[.]) then you probably wouldn't retrofit, and MC is probably the most common level to which a building is retrofitted.
- In the NBCC schools and community centres have importance factor of 1.3, designed 30% higher than normal importance. Post disaster buildings are 1.5 to ensure they are occupiable, functional, operational. Those are police, fire, emergency operations centres, hospitals.
- You can get benefits from URM retrofit, but it may not be all the way to MC.
- Mandatory retrofit programs are generally municipal (LA, San Francisco) not provincial/state/federal.
- New building codes are looking at performance-based metrics. Even HC aims for/allows extensive damage but no collapse. From an economic perspective, then, the goal is to have buildings which are HC or higher. MC is more like life safety. To have a resilient society that can stay in their homes, we need to aim for HC.

Response 7 – Email from Carlos Ventura, Ph.D., P.Eng., Professor of Civil Engineering at the University of British Columbia (March 10, 2021)

Some comments:

Occupancy:

In the Civic section, buildings that are used for educational purposes (like ESL schools) should be included somewhere. Convention centers could also be included.. [sic] Then, we also have the mixed-occupancy buildings (lower floors for commercial and upper floors for residential).

Construction Type:

When the Hazus taxonomy was developed, super-tall buildings were not that prevalent (40 stories plus) so I think we would need to eventually add a category for this type of construction. Currently, "high" means 8+ stories, so there is a huge gap on behavior between high, tall[,] and super-tall buildings.

Regarding retrofits:

The traditional way has been to retrofit a building to meet 60% to 80% of the current code - this is a very arbitrary way of doing it. The SRG for public schools provides a more rational approach, but it has been used mainly for schools and some other buildings in BC. There are other more "cosmetic-type" retrofits that deal mostly with non-structural and functional components, but do not cover the structural system. So[,] I think the schema should recognize that "retrofit" could mean many things, and from the context of the national model it should be made clear that retrofit objectives could be different, and yet would result in a reduction of seismic risk (not totally, but partially).

Given the short time, I can only offer these quick comments now, but I hope you find them useful.

Good luck with the project and let me know if I can be of further assistance.

Carlos

5. Summary

The responses above have a few common elements which will be discussed below. We defer any reference to the Seismic Design Level tab or its contents, as this document is interested only in the retrofit scheme. Likewise, we hold aside comments about the benefits and disadvantages of the current exposure or construction type database. Finally, we have investigated the most recent BC Housing initiative which is mentioned and find that it more so pertains to post-disaster building inspection than retrofits. We therefore thank the reviewers for their thorough comments but will defer those subjects to future works.

More than one respondent made it clear that seismic retrofits are relatively rare, and often only conducted during other alteration to the building. This is important to consider, however, our model is intended to allow a policy maker to assess the possible impact of future retrofits rather than any assessment of retrofits completed previously. For this reason, we find it safe to assume that this user is specifically motivated to consider retrofit as a standalone or co-measure. Along those lines, however, we agree that the retrofit scenarios being run by NRCan should be accompanied by clear guidelines for their implementation. For example, it would be an unrealistic use of these scenarios to consider the retrofitting of all buildings in the country, or for buildings in an area of low seismic risk. It is more appropriately invoked to consider the cost-to-benefit of retrofitting, say, pre-code high rise concrete buildings in a particularly damage-prone region of a metropolitan area along the West Coast or in the St Lawrence River.

Multiple respondents highlighted the need for consideration of the building's importance or supposed post-earthquake function. This is a very useful comment which can be included at least partially into the methodology using the existing occupancy codes. The most important occupancies are hospitals (COM6) and government emergency response buildings (GOV2), which we will treat using a HC exception that only allows a high-code retrofit.

Another particularly thought-provoking comment is related to the idea of a low-code threshold for buildings with unreinforced masonry structural elements. The point is raised that performing a retrofit to only a low-code level would seem somewhat illogical, even for notorious taxonomies such as precast or those with unreinforced masonry. In contrast, other feedback suggested that retrofitting to a moderate code level for these problem taxonomies would be unlikely to occur. While we are interested to explore this issue further, it is beyond the scope of this work. In future, NRCan will prioritize exploring existing retrofit-specific fragility and vulnerability functions (ex: Paxton et al., 2017, *Earthquake Spectra*) or supporting their development with collaborators. In the interim, NRCan will retain the LC threshold for URM, S5, and C3 taxonomies.

Finally, several respondents highlighted that, generally speaking, retrofits in high hazard areas of the country are often to 60-80% of the current code, approximately linked to the mid-code level. This is in line with the observation that generally it would be uncommon to perform a retrofit only to a low-code level. Although actual retrofit strategies are varied, it seems that the intended outcome most commonly sought would align best with the MC design level and that it would be uncommon for a building to be retrofitted to either LC or HC unless they have unreinforced masonry or are high importance, respectively. Therefore, we are adapting our retrofit schema to bring buildings to MC rather than the previous strategy of raising them by 1 or 2 levels. This applies to all buildings not covered in the HC exception and LC threshold described above.

In future, we will aim to conduct more optimistic retrofit scenarios which consider a possible future in which buildings could be encouraged to meet the current code regardless of post-earthquake status. This would allow one to ask the question: what is the maximum extent of the opportunity to reduce risk with retrofit measures? The results might be most immediately appropriate for public buildings like schools and community centres but could be expanded to other buildings to evaluate to usefulness of more ambitious existing building codes in the future. The current tool, unfortunately, doesn't allow a user to explore these higher performance objectives.

6. Conclusions

Respondents were kind enough to describe the current practices in seismic retrofitting and point out some of the potential benefits or shortcomings of different schemes for evaluating retrofits. Based on their feedback, the retrofit scheme for the Canadian Seismic Risk Model in 2021 will (1) assign any building with post-earthquake functions (COM6, GOV2) to high-code, (2) assign buildings with unreinforced masonry elements (URM, S5, C3) to low-code, and (3) assign any remaining buildings to moderate-code. This method shows us the realistic or plausible outcome of a retrofit, based on examples and current practice.

7. Acknowledgements

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Figures

Construction Material	Typology	Height	Wall Type	Design Epoch	LC Threshold	Baseline +1	Baseline +2
Concrete	C1H	> 8 Floors	C1: Moment Frame	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present		x	
	C1M	4-7 Floors				x	
	C1L	< 3 Floors					x
	C2H	> 8 Floors	C2: Shear Wall	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present		x	
	C2M	4-7 Floors				x	
	C2L	< 3 Floors					x
	C3H	> 8 Floors	C3: Masonry Infill	PC: < 1973, LC: 1974-1989t	x		
	C3M	4-7 Floors			x		
	C3L	< 3 Floors			x		
Manufactured	MH	< 2 Floors	MH: Light Frame	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present			x
Precast	PC1	< 3 Floors	PC1: Tilt-Up	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present		x	
	PC2H	> 8 Floors	PC2: Shear Wall	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present		x	
	PC2M	4-7 Floors				x	
	PC1L	< 3 Floors				x	
Reinforced Masonry	RM1M	4-7 Floors	RM1: Wood/Metal Diaphragm	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present		x	
	RM1L	< 3 Floors					x
	RM2H	> 8 Floors	RM2: Precast Diaphragm	PC: < 1973, LC: 1974-1989t		x	
	RM2M	4-7 Floors				x	
	RM2L	< 3 Floors					x
Steel	S1H	> 8 Floors	S1: Moment Frame	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present		x	
	S1M	4-7 Floors				x	
	S1L	< 3 Floors					x
	S2H	> 8 Floors	S2: Braced Frame	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present		x	
	S2M	4-7 Floors				x	
	S2L	< 3 Floors					x
	S3	< 3 Floors	S3: Light Frame	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present			x
	S4H	> 8 Floors	S4: Concrete Shear Wall	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present		x	
	S4M	4-7 Floors				x	
	S4L	< 3 Floors					x
	S5H	> 8 Floors	S5: Unreinforced Masonry Infill	PC: < 1973, LC: 1974-1989	x		
	S5M	4-7 Floors			x		
	S5L	< 3 Floors			x		
Unreinforced Masonry	URMM	4-7 Floors	URM: Unsupported	PC: < 1973, LC: 1974-1989	x		
	URML	< 3 Floors			x		
Wood	W1	< 2 Floors	W1: Light Frame	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present			x
	W2	3-6 Floors	W1A/W2: Light Frame			x	
	W3	< 4 Floors	W3: Heavy Frame	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present			x
	W4	< 2 Floors	W4: Light Frame/Cripple Wall	PC: < 1973, LC: 1974-1989, MC: 1990-2004, HC: 2005-present			x

Figure 1. A summary of building typologies used in the National Human Settlement Layer (Journeay et al., 2021), as well as the seismic design levels assigned by year. The right columns show the suggested retrofit assignment, which were sent to engineers and practitioners for feedback.