

ADDRESSING URM SEISMIC RISK IN VICTORIA, CANADA

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ABSTRACT

Victoria, British Columbia, Canada is widely known for its historical downtown core with numerous early 20th century masonry buildings. The city is also located within 100 km of the Juan de Fuca subduction zone, capable of approximately M9 mega-thrust earthquakes. The seismic risk for the region is further heightened due to the potential for smaller, but closer, crustal earthquakes. This seismic environment is not unlike that of Christchurch, New Zealand, where earthquakes in 2010 and 2011 have severely impacted the relatively large population of unreinforced masonry (URM) buildings. This paper briefly compares the history of heritage URM construction in Victoria with that in Christchurch and approaches taken to address the vulnerability of these buildings. Recognizing the life safety risk from these structures in the event of an earthquake, Victoria has taken a voluntary but proactive approach to the seismic retrofit of heritage buildings, including tax incentives. The paper reports on retrofit progress in Victoria, makes comparison to seismic risk mitigation efforts undertaken elsewhere, describes example projects, and introduces an ongoing study to correlate the distribution of URM buildings in the city with ground conditions and population distribution to identify the buildings with the greatest risk of damage in future earthquakes.

KEYWORDS: unreinforced masonry, seismic risk, seismic retrofit, Victoria, Christchurch

INTRODUCTION AND CANTERBURY EARTHQUAKES

The Canterbury Earthquakes of 2010-2011 have once again raised awareness of the vulnerability of unreinforced masonry (URM) buildings to severe damage and collapse in moderate and strong ground shaking and the immediate need for effective seismic mitigation policies. This lesson has reverberated strongly in Victoria, British Columbia, a community with many similarities to Christchurch, New Zealand, including colonial history, historic masonry construction practices, population (approximately 350,000), importance of tourism to the economy, and, most importantly, seismic hazard. Figure 1 provides the design response spectra used to determine seismic design forces for buildings on soft soils for Victoria and Christchurch for return periods of 475 and 2475 years. The similarities are obvious, particularly when it is considered that most URM buildings would be assessed to have a short period and hence the design earthquake forces in Victoria would be governed by the National Building Code of Canada (NBCC) short-period cutoff [1] shown in Figure 1, making the elastic design forces in Victoria only 9% higher than those used in Christchurch. Figure 1 also indicates that the demands from the 22 February 2011 Christchurch Earthquake were similar to the uniform hazard spectrum for a 2475 year return period, often referred to as MCE demands, for both cities.

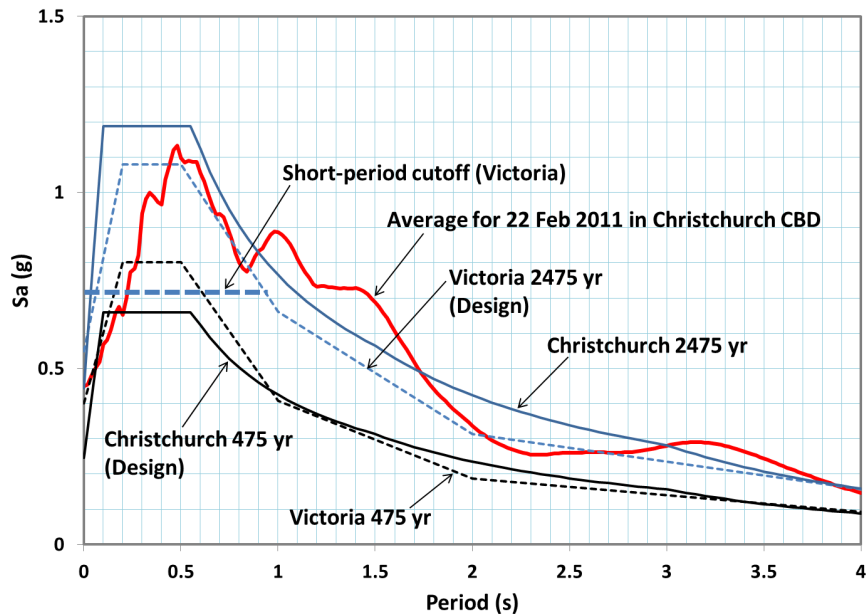


Figure 1: Comparison of design spectra for Christchurch and Victoria

Similar to many cities in seismically active regions, Christchurch City Council had initiated a passive earthquake strengthening program for URM buildings prior to the Canterbury Earthquakes, where changes in use or major alteration would trigger the need to retrofit existing buildings. After the earthquakes, 370 URM buildings were surveyed [2] to estimate the extent of retrofits achieved through this policy. The survey indicated that 22% of the buildings had comprehensive seismic retrofits (including strongbacks for out-of-plane wall support and/or supplementary in-plane bracing), 40% had partial retrofits (including connections between walls and wood diaphragms, with the remaining 38% not showing any evidence of seismic retrofit. To improve the economic practicality of seismic retrofits, it is common not to design for the full earthquake forces required by the building code for new buildings. Based on statistics collected by Ingham and Griffith [2], Figure 2 illustrates the observed performance of URM buildings with different levels of retrofits (relative to the design seismic forces required by the New Zealand Code) [3].

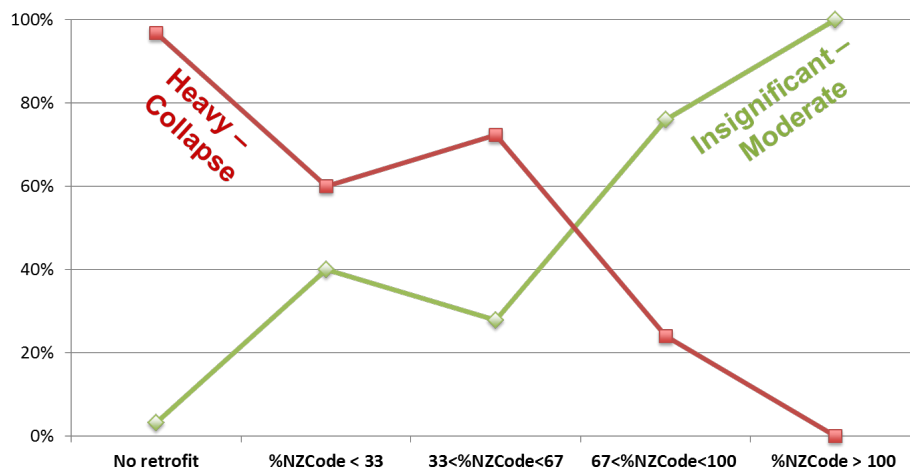


Figure 2: Relationship between retrofit level and observed damage from 22 February 2011 Christchurch Earthquake (data based on ATC-38[†] assessment [4] for 125 URM buildings from Ingham and Griffith [2])

[†]The assessment was based on ATC-13 damage classifications and made use of the ATC-38 data forms.

The results of the survey clearly indicate the improved performance of buildings with strong retrofits relative to those with no or limited retrofits. This lesson is not new, but the Christchurch Earthquake has presented an opportunity to raise awareness of the pressing need for seismic retrofitting of URM buildings internationally.

The remainder of this paper focuses on past and ongoing activities to address the significant seismic risk posed by heritage URM buildings in Victoria, BC, including an ongoing research project to identify and assess Victoria’s URM buildings and a comparison to URM seismic risk mitigation measures elsewhere in the Pacific Northwest.

THE HISTORY AND HERITAGE OF VICTORIA, BC

Incorporated in 1862, the City of Victoria (the City) is Western Canada’s oldest incorporated City, and was the most significant Colonial outpost, centre of commerce and military stronghold, which later became the capital city in the new province of British Columbia. Founded as the western headquarters of the fur trading empire of the Hudson’s Bay Company, the City grew exponentially in the latter part of the nineteenth century, fueled by the Cariboo and Klondike gold rushes. The City was eclipsed in the twentieth century with the arrival of the railway in Vancouver. As Vancouver expanded, Victoria’s economic prominence declined. Many of the important masonry commercial buildings in the City’s historic core were preserved as a result of this economic decline. In the 1970’s, the City began a sophisticated heritage program to conserve these important historic buildings in the core area known as “Old Town.” Figure 3 shows Victoria as well as the extents of Old Town and the area pilot study area for the aforementioned research project (discussed later in this paper). The city also established an arms-length, non-profit organization known as the Victoria Civic Heritage Trust (VCHT) in 1989 to deliver a program of financial assistance to the owners of protected heritage buildings in the downtown core. The vast majority of these buildings are URM buildings with timber diaphragms.

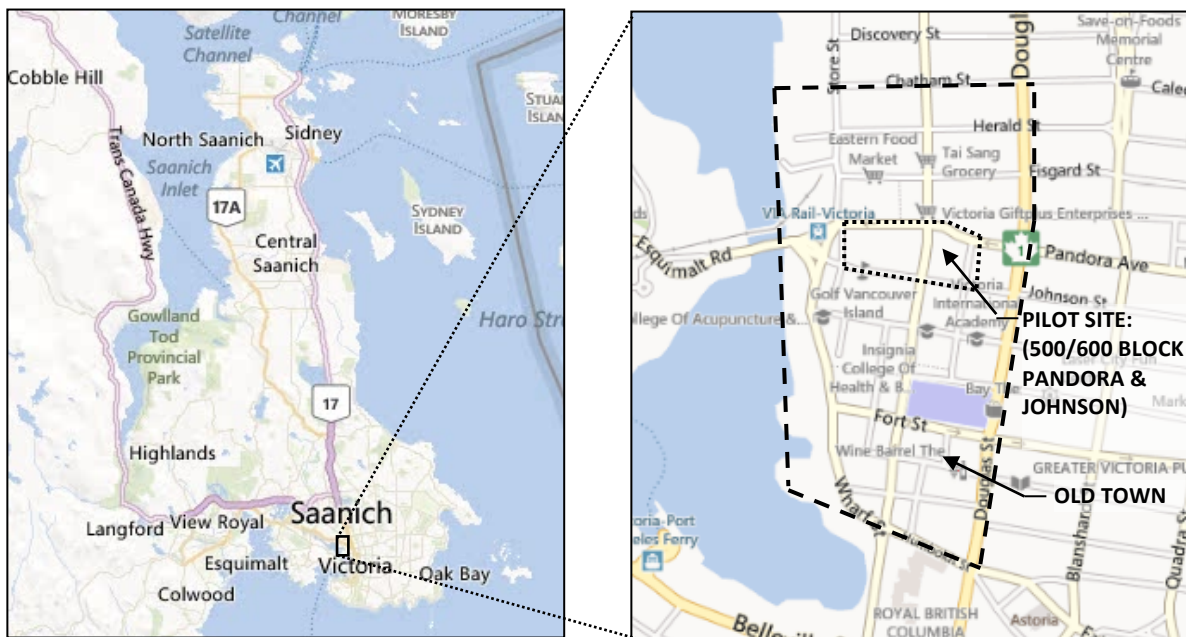


Figure 3: Study Area - General Location (Left) and Boundaries (Right)

SEISMIC RISK MITIGATION EFFORTS TO DATE

The VCHT operates the Building Incentive Program (BIP) which offers grants on a 50% matching fund basis up to \$50,000 to owners of heritage-designated commercial and institutional buildings in Victoria [5]. The purpose of the BIP grant is to promote the conservation and rehabilitation of the buildings; it does not specifically require seismic rehabilitation work, although structural and seismic upgrading work is given the highest priority when allocating grants. It also assists the City with the administration of the Tax Incentive Program (TIP) [5]. Started in 1998, this program provides a 10-year tax exemption to building owners to assist in the creation of new residential units on the upper floors of underutilized heritage buildings in the downtown core. The objective is to help offset the high cost of the seismic upgrading which is required by the BC Building Code as a result of the change of use or occupancy. Considered a major success, the program has stimulated the creation of over 600 residential apartments and attracted over \$205 million in private sector investment in 34 seismically upgraded and rehabilitated heritage buildings. The program has also been expanded to include non-residential applications, such as the seismic upgrades of office buildings.

Victoria has approximately 200 heritage buildings in the downtown core; this includes both “heritage-designated” buildings (protected by municipal bylaws and subject to City Council requirements in the case of alterations) and “heritage-registered” buildings (unprotected, but registered for monitoring and potential future designation) [6]. Since the introduction of the Tax Incentive Program in 1998, 34 buildings have received comprehensive seismic upgrading [7]. These include former warehouses, industrial buildings, hotels, a department store, a church, and a hospital [7].

While both the BIP and TIP programs have stimulated a considerable amount of seismic upgrading, the challenge for Victoria is the dozens of unreinforced masonry buildings which continue to operate with successful retail businesses on the ground floor, and no incentive to make seismic improvements. Due to the general lack of awareness of earthquake risks in British Columbia, building owners do not seem interested in actively pursuing the seismic upgrading of these vulnerable buildings. Nor is there any political leadership to create mandatory seismic upgrading. Some educational efforts have been made to increase community awareness, including the Victoria Heritage and Earthquakes Seminar in 1989 and the Seismic Retrofit of Heritage Buildings Conference in 1992. The City of Victoria has demonstrated leadership through its efforts to seismically upgrade its historic 1891 City Hall [8], an important heritage building of unreinforced masonry construction. Recently, public lectures in Victoria on the Christchurch earthquakes in New Zealand have helped raise awareness of the vulnerability of Victoria’s historic core area [9]. Effective programs for addressing seismic risk must include building support among politicians, building owners and the public by raising awareness of the vulnerability of Victoria’s valued heritage buildings to severe damage or destruction from major earthquakes.

EXAMPLE PROJECTS

A number of seismic retrofit projects in Victoria have involved innovative structural approaches. For the 1896 Leiser building, a former grocery warehouse located at 524 Yates Street which had been converted to offices, the developer was faced with a major seismic upgrading problem as his objective was to convert this building and an adjacent structure, the 3 storey 1900 Thomas Earle Warehouse, into residential apartments. The two buildings were separated by a courtyard

which provided the engineer the opportunity to utilize three large steel frames within the courtyard to provide lateral bracing for both buildings (Figure 4a), while not interfering with the internal layouts of the new residential apartments. The cost of the project was \$10.9 million, of which seismic upgrading was \$1.2 million with completion in 2007 [7].



Figure 4: a) Leiser & Thomas Earle Buildings (left); b) Chinese Empire Reform Bldg (right)

Another innovative approach was used in the rehabilitation of the 1905 Chinese Empire Reform Association building, a three storey Edwardian era building located at 1715 Government Street in Victoria's Chinatown (Figure 4b). The building retained much of its original historic interior on the third floor, including tongue and groove wood paneling on the walls and ceiling. The second floor had suffered a fire in the 1960's and had been substantially altered. The seismic upgrading strategy devised by the owner was designed to retain as much of the original interior historic fabric as possible. Therefore plywood diaphragms were designed for the second storey to be installed on the floor and the ceiling below the third storey so the original fir floor on the third floor could be preserved. The tongue and groove fir panelling was carefully removed and reinstated to allow for steel strong backs to be installed to brace the side brick walls. A steel frame was constructed to be inserted behind the façade and was designed with a three-inch tilt to accommodate the settlement of the structure which had occurred over time. The entire roof and attic structure was removed and replaced to facilitate seismic upgrading. The project received a President's Award in 2012 from the Hallmark Heritage Society [10].

Several other buildings have received assistance through the BIP for partial seismic upgrades [7]:

- In 1993, a \$50,000 grant was given to the owner of the 1892 Board Of Trade building, an office building, to seismically brace the front brick and stone façade.
- In 2008, the owner of a small 1860 commercial brick building at 536 Yates Street discovered cracks in the parapet wall; he approached the City for permission to undertake repairs and was persuaded to engage an engineer to add steel bracing and seismic anchors to brace the parapet after its reconstruction. Financial assistance was secured through the VCHT.
- In 2010, the owners of the 1889 Green block at 1210 Broad Street received a \$50,000 grant from the VCHT to assist with a roof replacement project. They also took advantage of this construction project to undertake a voluntary seismic upgrade of this 2 storey

unreinforced brick masonry commercial structure. The engineer on this project introduced a reinforced concrete parapet at the top of the brick wall. While it was only a partial upgrade to the building, it demonstrates the opportunities for seismic improvements which can be undertaken as part of other building improvements.

- In 2011, the owner of the 1884 Galpin Block at 1017 Government Street took advantage of a vacant retail storefront to introduce diagonal steel bracing to reinforce the open front.

Such opportunities are an excellent example of how voluntary, modest improvements can add to the public safety of city streets; however, further efforts are clearly needed to address the seismic risk posed by the more than 150 heritage buildings still unretrofitted in Victoria's downtown core. Moreover, Victoria does not currently have an inventory of all URM buildings in its jurisdiction, aside from the basic information on the approximately 200 heritage buildings (not all of which are of URM construction). Without a purpose-built inventory of URM buildings, assessing and mitigating their related seismic risk is difficult.

COMPARISON TO URM SEISMIC RISK MITIGATION IN OTHER JURISDICTIONS

The 34 buildings upgraded through the Tax Incentive Program represents about 17% of all the heritage buildings in downtown Victoria, achieved over a period of 14 years. This has been a voluntary program, but it may be necessary for legislative authorities to consider some form of mandatory upgrading of URM structures, such as those undertaken in California.

In 1976, the city of San Francisco enacted its Parapet Safety Program, which required bracing of having excessive height-to-thickness ratios and roof-to-wall connections; it applied to all pre-1949 URM buildings posing fall hazards to public sidewalks or occupied spaces [11].

In 1986, the State of California passed the well-known "URM Law" [12]. The law applies to approximately 26,000 URM buildings in areas of highest seismic hazard under the California Building Code (based on the 1985 Uniform Building Code at the time the law was passed), Seismic Zone 4, and required 365 affected local governments to: inventory URM buildings, establish loss reduction programs, and report on progress [13]. The law recommends, but does not require, that local governments include mandatory strengthening in their loss reduction programs. Voluntary strengthening and notification-only programs also meet the requirements of the law.

Mandatory strengthening programs generally required comprehensive upgrading for in-plane and out-of-plane seismic demands [13]; the most commonly used standard is Appendix Chapter 1 of the Uniform Code for Building Conservation (UCBC) [14]. Other mandatory programs required only partial retrofits to limit economic impacts on the community. The most significant example is the "bolts plus" provision of San Francisco's ordinance 225-92, of July 1992. The ordinance, which mandated retrofitting/abatement of approximately 2000 identified URM bearing wall buildings, included a relaxation for URM buildings not containing certain occupancies (assembly >300; educational; institutional; or high-hazard) and having a regular configuration, sufficient crosswalls, and percentage of solid wall [15, 16]. This "bolts plus" relaxation called for just diaphragm-to-wall connections (for shear and tension) and out-of-plane bracing for walls exceeding specified height-to-thickness ratios. Those buildings not qualifying for the relaxation (and not being demolished) required retrofitting in accordance with the Uniform Code for Building Conservation, Appendix Chapter 1, similar to other mandatory programs.

Voluntary strengthening programs typically encouraged comprehensive upgrading, similar to the mandatory requirements noted above.

Notification-only programs typically included only a letter of the local authority having jurisdiction to buildings owners, stating that their building is of URM construction and is a potential seismic risk.

Of the 365 affected local governments, 283 were found to have URM buildings in their jurisdiction. The majority of these have adopted mandatory strengthening programs. Table 1 summarizes the loss reduction program types established as of 2006 [13]:

Table 1: California URM Loss Reduction Program Statistics

Program Type	No. of Jurisdictions	Percent	No. of URM Bldgs	Percent
Mandatory Strengthening	134	47%	19,043	73%
Voluntary Strengthening	39	14%	1,269	5%
Notification-Only	46	16%	1,487	6%
Other [†]	41	15%	3,737	14%
No Program Established	23	8%	409	2%
Total	283	100%	25,945	100%

[†]Combinations and variants of the above noted approaches

As of 2006, approximately 55% of the affected URM buildings had been retrofitted and 15% had been demolished, for an overall mitigation rate of 70%. Table 2 shows a breakdown of the results for each program type [13]:

Table 2: California URM Risk Mitigation Statistics

	Mandatory	Voluntary	Notification Only	Other	Not in Program	Total
No. of Jurisdictions	134	39	46	41	23	283
No. of URM Bldgs	19,043	1,269	1,487	3,737	409	25,945
% Retrofitted	70%	16%	7%	15%	4%	55%
% Demolished	17%	8%	6%	11%	27%	15%
% Mitigated (Retrofits + Demo's)	87%	24%	13%	26%	31%	70%

The statistics show that mandatory strengthening requirements results in a much higher mitigation rate than do either voluntary or notification-only programs. In comparing these results to the aforementioned statistics for Victoria, the 17% retrofit rate of downtown heritage buildings appears comparable with the success of the voluntary strengthening programs of California. It should be noted that the Victoria retrofit rate accounts only for comprehensive seismic upgrades, whereas the California statistics (particularly the Mandatory category) include partial retrofits [13]. It should also be noted that the Victoria statistics include only designated or registered heritage buildings.

The statuses of URM seismic risk mitigation in other areas throughout the Pacific Northwest are more similar to that of Victoria. In Seattle, Washington, an inventory survey of URM buildings

was recently completed by the Department of Planning and Development (DPD) [18]; this survey built on a past surveys completed for the DPD [19, 20]. Approximately 800 buildings were identified, 10% to 15% of which appeared to have received some degree of seismic upgrading. Recognizing the risks associated with unretrofitted URM buildings, the City of Seattle passed ordinances requiring retrofit of all URM buildings in the early 1970s; however, the ordinances were repealed couple of years later due to the high cost to building owners of implementing the upgrades. Currently, comprehensive seismic upgrading is only triggered by changes of use or occupancy, similar to Victoria. In contrast, Section 3401.8 (“Unsafe Building Appendages”) of the Seattle Building Code states that “*Parapet walls, cornices...that are in a deteriorated condition or are otherwise unable to sustain the design loads...are hereby designated as unsafe building appendages*” and “*shall be abated in accordance with Section 102 [21].*” This is essentially a narrowing of focus of the general “unsafe condition” clause (in this case Section 102) that is present in most building codes. Unfortunately enforcement of this clause has reportedly been limited. However, development of URM risk mitigation policies is underway in Seattle; recent draft documents indicate that comprehensive mandatory upgrading is being considered, with relaxations to partial upgrading requirements for certain buildings and incentive programs to assist with financing [22].

In Portland, Oregon, a URM survey was completed in the early 1990’s [23] and a 2007 seismic-needs assessment for public buildings in Oregon included a survey based on FEMA 154 [24]; this survey included all types of structures, rather than solely URM. Approximately 1800 URM buildings have been identified; the rate of retrofit in Portland is thought to be similar to Seattle [25]. Similar to Seattle and Victoria, comprehensive seismic upgrading is only required as part of a change of use or occupancy. The Portland City Code also has a retroactive parapet ordinance in effect requiring retrofitting when roof repairs or replacement are undertaken [26]. The ordinance was first adopted in 1994, but statistics on the rate of retrofit of parapets have not been compiled.

Vancouver, British Columbia does not have an inventory of URM buildings, similar to Victoria. However, Vancouver has incorporated a comprehensive section on existing buildings into its building code, the Vancouver Building By-law (VBBL) [27]. Part 10 – Existing Buildings of the VBBL and Appendix includes triggers clearly indicating when seismic upgrading is required and to what extent. In addition to the traditional triggers of change of use/occupancy and “significant improvements” (defined on the basis of anticipated project costs and the assessed value of the building), Part 10 defines upgrade scenarios triggered by repairs, reconstruction, as well as “Minor” and “Major” renovations and additions [28]. For renovations and certain changes to lower risk occupancies, seismic requirements would, at most, require securing non-structural items and falls hazards. For major vertical additions and reconstruction, comprehensive seismic upgrading to achieve at least 75% of the code-specified force demands would be required if the building currently possesses less than 60% of the required resistance. One of the basic requirements of the By-Law is there cannot be any increase in non-conformity with the bylaw and all new work needs to comply with the Bylaw. Some flexibility is adopted based on hardship and the difficulty and impact of meeting higher levels of seismic performance. There are no statistics available for the number of retrofits achieved under this trigger-based program.

Overall, the efforts to identify and mitigate URM seismic risk in Victoria are considered to be lacking in comparison to other regions of the Pacific Northwest. While the incentives for

voluntary comprehensive seismic upgrading of heritage buildings have been somewhat successful and the city requires seismic upgrading as part of a change of use/occupancy, a comprehensive survey of URM buildings in Victoria has not been performed and risk mitigation measures are not in place to effectively address occupied buildings; nor are there currently provisions for partial seismic upgrading of buildings to address the most pressing and easily corrected issues.

Table 3 provides a summary of URM seismic risk mitigation measures throughout the Pacific Northwest. Note that for some regions such as Seattle the measures have not been finalized, but the intent is to show the general trends in activity. Only selected jurisdictions in California are shown here, but there is a great variety among the 283 affected jurisdictions with URM buildings. Reference [29] provides a detailed overview of the California jurisdictions in question.

Table 3: Summary Table of URM Seismic Risk Mitigation by Region

Jurisdiction	URM Inventory	Retrofit Requirements	Triggers	Parapet Bracing Ordinance
San Francisco, California	Yes (Mandated)	Yes (Mandatory)	All except: residential w/ < 5 units, or in compliance with SF code c. 1973	Yes Blanket Ordinance (Enacted 1976)
Oakland, California	Yes (Mandated)	Yes (Mandatory)	Pre-1948 except: residential w/ < 5 units, or upgraded to code after 1948	Yes Blanket Ordinance (Date Unknown)
Palo Alto, California	Yes (Mandated)	Yes (Triggered)	Change of Use/Occupancy or improvements	No Specific Ordinance
Seattle, Washington	Yes	Yes (Triggered) <i>Proposed Mandatory</i>	Change of Use/Occupancy or improvements	Yes Building Specific (Enacted c.1965)
Portland, Oregon	Yes	Yes (Triggered)	Change of Use/Occupancy or improvements	Yes Triggered (Enacted 1994)
Vancouver, British Columbia	No	Yes (Triggered)	Change of Use/Occupancy or improvement (detailed triggers system)	No Specific Ordinance
Victoria, British Columbia	No	Yes (Triggered)	Change of Use/Occupancy or improvements	No Specific Ordinance

ONGOING STUDY – SEISMIC RISK ASSESSMENT OF URM BUILDINGS

Identifying seismically vulnerable buildings is obviously a critical step in mitigating their associated seismic risk. Past studies and risk assessment guidelines have identified unreinforced masonry buildings as a primary threat in terms of both life safety and economic losses [30, 31, 32]. In the wake of the 2010/2011 Canterbury earthquakes, 85% of the buildings demolished in Christchurch were of URM construction [33] (however, it should be noted the region facing the highest seismic demands had an above-average concentration of URM buildings). Furthermore, a joint report from the Universities of Auckland and Adelaide noted that it was essential to public life safety that local building authorities have a register of URM buildings located within their jurisdiction [33]. Perhaps more importantly, the buildings must be identified in a way that is

readily accessible to and prominent amongst decision-makers, so that their risk can remain at the forefront of competing agendas.

In an effort to promote voluntary seismic upgrading of parapets and facades, the VCHT has developed a new Parapet Incentive Program (PIP) and has commissioned a study to identify vulnerable URM buildings and assess their associated seismic risk. The study will focus on Victoria's historic "Old Town" (Figure 2). As aforementioned, a pilot program is to be run for the 500 and 600 blocks of buildings between Johnson Street and Pandora Avenue in the downtown core, starting in January 2013. An outline of the study is provided herein.

In order to assess the seismic risk, a building database must first be generated. As is common for heritage URM buildings in Victoria, existing documentation is scarce; thus, screening reviews of each building will be performed to confirm and update data such as construction type, number of storeys, irregularities, occupancy, the presence of fall hazards such as unbraced parapets, and any renovations or seismic retrofits. The study will combine this building information with data on seismic hazard, soil type (site class), and occupant/pedestrian exposure to quantify each building's seismic risk. A preliminary estimate of risk will be made for each building based on the document, *FEMA 154* [34], which estimates the probability of collapse for a given seismic demand by means of a prototype-based scoring system. The results will be mapped using GIS software and will be integrated with the City of Victoria's existing database in order to ensure the results are readily accessible to decision-makers. The intent is for the database to be a living document that can be readily updated with future information as additional scope and detail are captured.

The study will attempt to recommend appropriate measures for retrofits and the establishment of loss reduction programs, as is currently being investigated in Seattle. A primary goal of the study is to provide the Victoria Civic Heritage Trust with an estimate of the level seismic demand up to which various degrees of upgrading offer significant improvements to loss mitigation. The intent is to offer cost-benefit insight to promote voluntary seismic upgrading under VCHT's new Parapet Incentive Program and to help ensure these important initiatives remain at the forefront of agendas of key decision-makers. The effectiveness of common retrofit details, such as the performance of adhesive anchors as revealed by the 2010/2011 Canterbury Earthquakes will be reviewed.

The study will also be used to improve a more broad seismic risk assessment: a wide-reaching seismic loss assessment study for Greater Victoria is currently being undertaken by researchers at Simon Fraser University. This study employs the newly developed HAZUS software for Canada [35, 36] and addresses all building types throughout Greater Victoria, in addition to other components of the built environment. Because the URM study focuses on a specific type of building structure, an effort to develop or improve upon specific assessment methods will be viable. An attempt will be made to provide data and conclusions about URM buildings that could aid in refining the HAZUS loss assessment. As unreinforced masonry is the prevalent construction type throughout nearly all of Victoria's "Old Town" [30] – which also happens to be its central business district – and URM buildings are known to be one of the most significant contributors to earthquake losses, the opportunity to refine this small portion of the broad loss assessment is thought to be valuable.

Ultimately, the study will contribute to the advancement of seismic risk assessment practices in the region and will provide heritage societies, buildings owners, and other stakeholders with a decision-support and risk management tool to promote the seismic upgrading of heritage buildings and improve life safety in the downtown core.

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