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Influence of the V_{s30} mapping on the residential risk; Case study of the Greater Montreal

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ABSTRACT

This study highlights the impact of site conditions on estimates of seismic losses for residential buildings in the Greater Montreal area and the importance of defining region-specific seismic microzonation maps. Recent alluvial deposits from the Saint-Lawrence River and clay deposits from the Champlain Sea overlaying glacial tills and bedrock characterize this region. The thickness of the post-glacial layer, which can reach up to 50 m, plays an important role in the level of seismic hazard for a given site and consequently for the loss estimates. A microzonation map has been developed in terms of V_{s30} based on shear-wave profiles, indirect seismic measurements of ambient noise and boreholes data. This map, used as benchmark, is compared to one estimated from the US Geological Survey (USGS) approach that considers as a proxy the slope topography in order to estimate V_{s30}. The USGS-approach map is calculated on a regular spatial grid of 0.02 degrees (approximately 2 km) worldwide. We consider both maps to re-calculate the hazard values from the 2020 Canadian seismic hazard model provided by Natural Resources Canada (NRCan) for the return period of 2475 years in the center of the 6100+ dissemination areas in the Greater Montreal area. The resulting shakemaps are used in OpenQuake with our exposure data for residential buildings and vulnerability models provided by NRCan. The USGS-based microzonation is shown to overestimate Peak Ground Acceleration, spectral acceleration Sa(0.3s) and Sa(1.0s), by 7, 20 and 27 % on average respectively. The increase in terms of total losses for residential buildings is of 30% on average.

Keywords: V_{s30} mapping, risk analysis, residential buildings, Greater Montreal, SHM6, USGS

INTRODUCTION

Soft soil can have a significant influence on ground motion during an earthquake as attested by many observations on the distribution of ground motion and associated building damage from past earthquakes (e.g. [1]). The low density and rigidity of soft soil induce changes in the amplitude and wavelength of seismic waves as they travel through this medium. This can have negative effects by increasing the level and duration of ground shaking causing more damage to structures than would have been expected otherwise [2]. Thus, local site conditions can lead to variable ground motions at similar epicentral distances. Therefore, locating and characterizing soft soil deposits is important for assessing seismic hazard and estimating potential risk.

One of the parameter commonly used to define site conditions is the average shear-wave velocity of the top 30 m of soil, V_{s30} [2]. It is used to classify sites into five classes from A to E where A is hard rock with V_{s30} higher than 1500 m/s and E soft soil with V_{s30} lower than 180 m/s. A worldwide V_{s30} model is provided by the US Geological Survey (USGS), which is based on the slope topography on a regular grid of points [3]. This model is an adequate proxy at large spatial scales but needs to be calibrated at regional scales (e.g. [4, 5]).

Indeed, at the local scale of the region of Montreal, the USGS model is largely dominated by the ancient flat topography of the Champlain Sea, which results in large expanses of low V_{s30} areas. For this region, information derived from seismic surveys, boreholes datasets and geological maps has led to a high-resolution V_{s30} model [6]. The outcropping rock in the geological maps delineates the location of hard rock sites. Soil profiles from boreholes were converted to Vs profiles by considering the main soil types and corresponding Vs-depth relations derived from compilations of seismic data [7, 8]. Similarly, resonance frequencies obtained from ambient noise records were converted to V_{s30} values by considering V_{s30} relations derived from compilations of these seismic data [9].

The 6th generation seismic hazard model (SHM6) has been developed to provide seismic design spectrums for the 2020 National Building Code of Canada (NBCC2020). Besides the update of the earthquake catalogue and seismic source models [10], major changes are related to the introduction of recently developed ground motion models and the application of an expanded logical tree to model epistemic uncertainties [11]. It is also the first time the seismic hazard can be calculated directly based on the value of V_{s30}. This change is intended to replace the use of amplification factor F(T) tables used in the previous NBCC edition in order to directly calculate the seismic hazard at a specific site. SHM6 was used to estimate hazards at the level of census dissemination areas (DA) for both the USGS and the detailed microzonation maps.

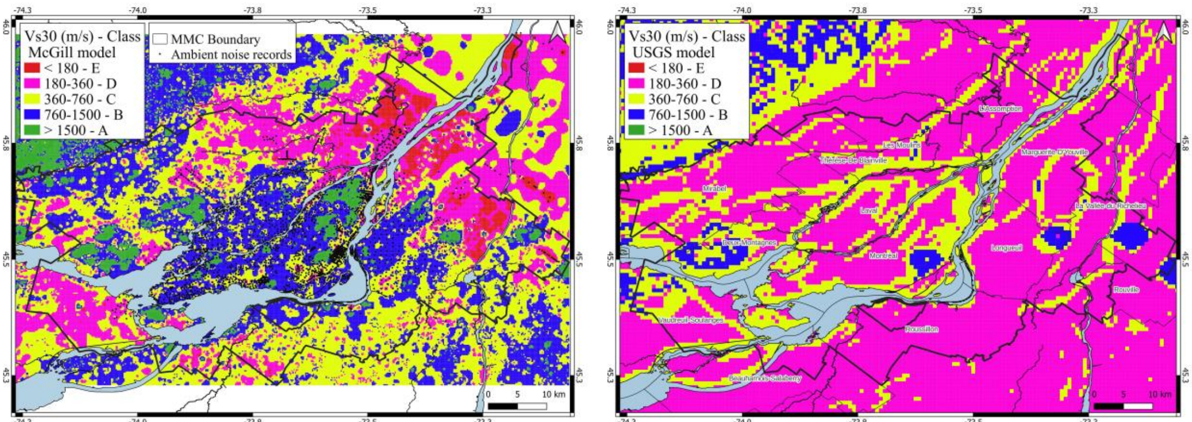
The exposure model for Greater Montreal combines information on residential buildings from property assessment roles, knowledge on local building typology, and insurance industry data on insured content. The vulnerability model used for the analysis is the one used by Natural Resources Canada (NRCan) for national level risk assessments (Hobbs et al. [12]). The model includes loss ratio curves for structural, non-structural and content for Peak Ground Acceleration (PGA) and spectral acceleration Sa(T) at the periods T of 0.3, 0.5, 0.6 and 1.0s for building typology as defined in Hazus [13]. The OpenQuake (OQ) engine (available under https://platform.openquake.org/) is selected to calculate losses at the scale of DA for the SHM6 (at the return period of 2475 years) and the two V_{s30} models. We then evaluate the influence of the two site condition models on the residential building losses.

METHOD

Input V_{s30} models

V_{s30} is one of the most common parameters to define site conditions that is ideally obtained from geophysical measurements of Vs derived from invasive and non-invasive methods (e.g. [14]). In the region of Montreal, we combine a dataset of more than two thousand interpreted seismic ambient noise records with Vs seismic refraction and reflection profiles in order to correlate the frequency of the peak resonance in the calculated horizontal to vertical Fourier spectrum and the estimated V_{s30} in each profile [9]. These sites were complemented with an interpretation of thousands of borehole profiles in terms of V_{s30} considering typical soil layers (backfill, clay, sand, till and rock) and a depth-dependent Vs profile for these soils [7]. Contours of the rock are from surficial geological maps. The map in Figure 1a shows the final interpolated V_{s30} values over the Greater Montreal region grouped into site classes from A to E. The latter is referred to as the detailed microzonation model hereafter.

The second V_{s30} model used in this paper is the one obtained from the proxy of the slope topography, proposed by Wald and Allen [15], and updated by Heath et al. [16]. The USGS model is available on a worldwide regular grid with a resolution of 30 arc-seconds, corresponding approximately to a cell size of 2 by 2km in our case. The USGS site model was used in recent risk analyses for Canadian cities [17] and regions [12]. It assumes that a large extent of the greater Montreal area is of soil class D (Figure 1b) and has a much lower resolution that the detailed map.



(a) *(b)*

Figure 1. Site models in Greater Montreal in terms of V_{s30} (in m/s) grouped in site classes from (a) the detailed and (b) the USGS data.

The adaptation of the SHM6 to consider variable V_{s30} values grid

SHM6 is fully implemented within the OpenQuake platform and uses the site location (latitude and longitude) and site class (value of V_{s30}) as input for hazard calculations. The SHM6 Open File Report [18] provides the input for the hazard calculations with OQ for any locality in Canada. However, the version available when the study was performed only provides ground motion model tables for a set of specific V_{s30} values (140, 160, 180, 250, 300, 450, 580, 760, 910, 1100, 1500, 1600, 2000, 3000 m/s). For our purposes, a mean V_{s30} value was calculated within each DA using both site condition models and the corresponding nearest lowest value in the SHM6 tables was used to calculate the seismic hazard in terms of PGA and Sa(T) for all locations with the same range of V_{s30}. This procedure has been repeated for all DAs and ranges of V_{s30} values provided in the SHM6.

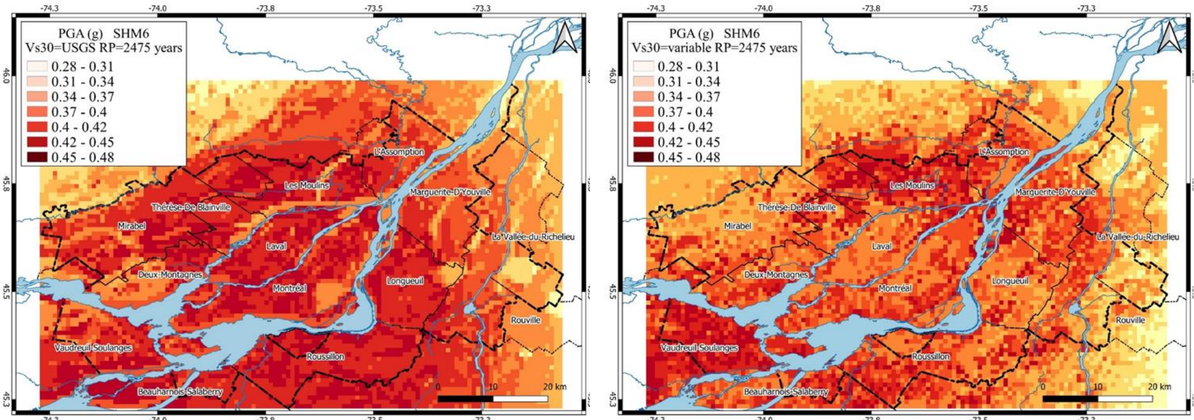
The Risk model for Greater Montreal

The exposure model used for the calculations is developed at the scale of the 6000+ DA using the information from the property assessment role. A detailed analysis and survey in the island of Montreal characterizes building types as a function of construction material, occupancy, year of construction, the geographical location, number of dwellings, and number of floors [10]. The occupancy types (number of dwellings) and construction types (wood, masonry, steel, concrete or mobile house) define all residential buildings in Greater Montreal following the rules applied in Montreal and later grouped and counted by DA. The year of construction is a key indicator to express the level of resistance of a building because it is directly connected to the different versions of the national building code. We consider two main dates that are the first version of the national building code (1970) and its important update in 1990. The buildings built before 1970 are grouped in the pre-code level of the vulnerability curves as the ones built after1990 are classed in the moderate-code level. Low-code level is attributed to the buildings built in-between period. The vulnerability curves used in this analysis are the one adopted by Hobbs [17] in three risk scenarios in Canada and in the scenario catalogue for Canada [12].

RESULTS

Variations of PGA, Sa(0.3s) and Sa(1.0s) using USGS and detailed V_{s30} models

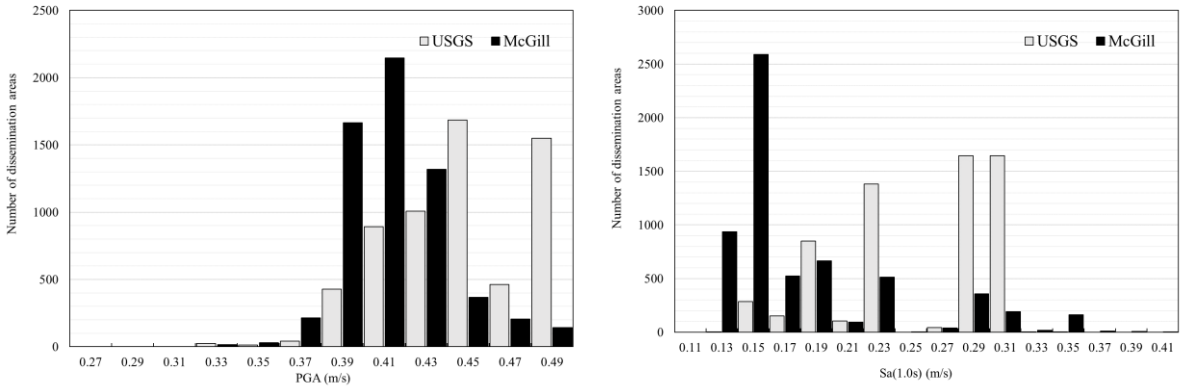
Maps in Figure 2 show the calculated PGA on the regular grid using the USGS and McGill V_{s30} models respectively. The extent of highest values (PGA > 0.4g in red colors) is much larger with the former than the latter models. Indeed, the average value of PGA, Sa(0.3s) and Sa(1.0s) in the region increases by 5, 16 and 28 %; respectively when using the USGS model. When the ground motion values in the grid are averaged over each DA in Greater Montreal, the average increase is of 7, 20 and 27 %. The largest difference is found in NW-SE axis crossing Laval, the island of Montreal and Longueuil.



(a) *(b)*

Figure 2. PGA (in g) calculated on a regular grid using SHM6 for the return period of 2475 years (probability of exceedance of 2% in 50 years) integrating the V_{s30} data in Figure 1 from (a) the USGS and (b) the detailed maps.

The graphs in Figure 3 distribute by bins the PGA and Sa(1.0s) averaged by DAs for both USGS (grey color) and detailed (black color) models. The median values with the latter model are 0.4g, 0.45g and 0.14g for PGA, Sa(0.3s) and Sa(1.0s), respectively, and 0.43g, 0.63g and 0.28g with the USGS model.

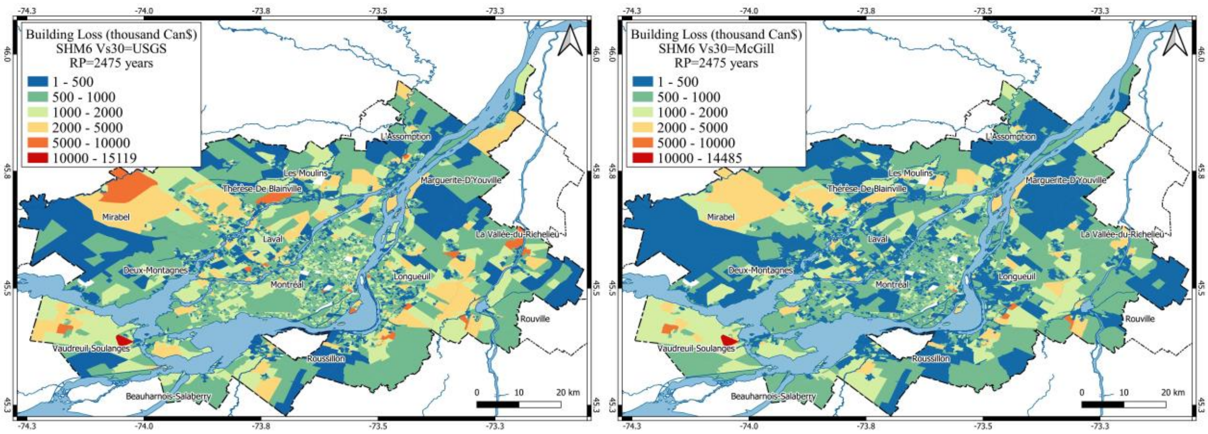


(a) *(b)*

Figure 3. Distribution of calculated (a) PGA and (b) Sa(1.0s) by DAs using SHM6 for the return period of 2475 years (probability of exceedance of 2% in 50 years) and the V_{s30} models from USGS and McGill.

Differences in the loss estimates

The calculated hazard by DA for PGA and Sa(T) at periods T of 0.3, 0.5 and 0.6s using both V_{s30} models (e.g. the PGA maps in Figure 2) serve as input for the damage and loss calculation with OQ using the exposure and vulnerability models described in the section "method". The maps in Figure 4 show the distribution by DA of building loss (from structural and non-structural damage) based on the input hazard grids calculated with the two V_{s30} models. The loss map using the USGS model includes a larger number of DAs with value higher than 5 million Can$ (23) than the one using the detailed model (7). The number of DAs with loss lower than 500,000 Can$ is reduced by 70% with the USGS model and increased by a factor of two for loss ranges between 1 and 10 million Can$. The median value is 536,000 Can$ with our model as it is 690,000 Can$ using the USGS model, this value representing more than 72% of the total loss median value.



(a) *(b)*

Figure 4. Residential building loss by DA calculated using SHM6 for a probability of exceedance of 2% in 50 years integrating the V_{s30} data in Figure 1 from (a) the USGS and (b) the detailed maps.

The table 1 lists the total losses obtained with the two models (USGS and detailed) separated into building structural, non-structural damages and content losses. It shows an increase of 30% in average of the losses for residential buildings in Greater Montreal if one uses the V_{s30} proxy model of the USGS instead of a local site condition mapping.

Table 1. Residential building loss using USGS and detailed V_{s30} models and SHM6 (2% probability of exceedance in 50 years).

Types of loss	**Residential building loss (in million Can$)**		**Total building value (in million Can$)**	**Increase rate (%)**
	Detailed map	USGS map		
Structural	855	1,061	28,551	20
Non-Structural	2,988	3,904	167,953	30
Content	1,466	2,017	99,030	40
Total	5,309	6,981	295,534	30

CONCLUSIONS

This paper aims to compare the losses calculated for residential buildings in the Greater Montreal region considering the SHM6 for a return period of 2475 years and the site conditions (in terms of V_{s30}) at two levels of resolution, one from the USGS developed at the global scale and a more detailed map based on site-specific data. The former model underestimates V_{s30} values compared to the more accurate zonation and increases the ground motions in the probabilistic seismic hazard analysis (from 7% to 27% increase in average for increasing spectral acceleration periods). Considering our site conditions and exposure model as a benchmark, this overestimation of ground shaking results in an increase of about 30 % in the residential building losses. This preliminary analysis highlights the importance to consider an accurate site condition mapping, especially in urban areas with recent soft soils deposition when performing risk analysis.

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