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Damage Estimates Due to Earthquakes in Montreal using an Hybrid Version of HAZUS

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Abstract: In Canada, Montreal is the second city at risk considering its population and the probabilistic seismic hazard. Scenarios of earthquakes are proposed to estimate building damage and related fatalities using a hybrid version of HAZUS. Ground motion estimates are based on the deaggregation of the seismic hazard (2% in 50 years) for three different Ground Motion Prediction Equations (GMPEs) as well as an advanced microzonation mapping to incorporate site effects. Individual building taxonomy is extracted from the evaluation roll of the city of Montreal (2009). Population data is divided in 522 census tracts (2006) and occupancy rates are determined for 3 different times of the day using data from an Origin-Destination survey (2003). Due to limited access to proprietary data, the Montreal study is focused on direct physical damage to the general building stock and essential facilities, estimation of the number of casualties, shelter needs projections and direct economic losses. Preliminary results show that masonry building is the most vulnerable building type and downtown Montreal is the most vulnerable area. The choice of GMPEs is shown to be one of the most important parameter contributing to the uncertainty of the results.

1 Introduction

Montreal is the largest city in Quebec, and the cultural and economic center of the region. Although the seismic hazard is moderate, the city is ranked as the second city at risk in Canada considering its population (Adams et al., 2002) and its aging infrastructure. Since a decade, extensive analysis of the local seismic hazard and vulnerability of specific infrastructures have been engaged (Chouinard et al., 2013; Rosset and Chouinard, 2009) but no damage and losses estimates were available. Keyan et al. (2013) propose a first analysis which is summarized in the present paper. The results of such studies provide decision makers with an overview of the damage due to major earthquake that could also be used as input data for mitigation planning ahead of time. A full impact assessment requires the analysis of all components involved in a seismic event: namely building stock, transportation system, infrastructure system and critical facilities. However, the collection of such data is often costly and time-consuming. Therefore, this project focused on the damage of building stock and its corresponding social-economic impacts. The analysis is carried out using HAZUS-MH4 software (FEMA, 2003).

2 Data Collection

A range of data was collected for this project including seismic hazard, building inventory and demographics as Listed in Table 1.

Table 1: List of data collected and used as HAZUS input

Data Category	Input map or data	Input parameters
Seismic Hazard	Ground Motions Maps for scenarios	PGA, PG, Sa_1s and Sa_0.3s
PESH (Potential Earth Science Hazard)	Soil Classification Map	V_{s30}
	Liquefaction Susceptibility Map	Indicator of susceptibility
	Landslide Susceptibility Map	Indicator of susceptibility
Building Inventory	General Building Stock	Area
		Building Value
		Structural Type
		Occupancy Class
		Age or Year of Construction
	Essential Facilities	Location
Demographics	Household and Income	Household Number and Income
	Population	Values at 2am, 2pm and 5pm

In order to take into account the variability of the expected ground motions, 38 Scenarios of earthquakes are proposed based on the deaggregation of the seismic hazard (for a exceedance probability of 2% in 50 years) using three different Ground Motion Prediction Equations (GMPEs) developed for Eastern North America (Atkinson, 2008; Atkinson and Boore, 2006; Boore and Atkinson, 1995). For each scenario, a set of ground motion contour maps (PGA, PGV and spectral acceleration Sa at 1 and 0.3s) is created using the selected GMPEs and an advanced microzonation mapping to incorporate site effects. Liquefaction and landslide susceptibility is also considered following the HAZUS recommended methods. Individual building taxonomy is extracted from the evaluation roll of the city of Montreal (2009) which includes total building area, building height, age of construction and building occupancy class. Demography data, divided into 522 census tracts, are obtained by the 2006 census survey. Data from the 2003 Origin-Destination (OD) survey were also used to determine the population distribution in the city at 3 different times of the day (2a.m., 2p.m. and 5p.m.). All data collected are tabulated to be compatible with HAZUS. The output of HAZUS for each scenario includes direct physical damage of general building stock and essential facility, direct economic losses, and casualty estimates.

3 Results and Discussion

A weighted average damage is calculated using results from the 38 individual scenarios. The weight of individual scenario is based on its relative importance from deaggregation of the target seismic hazard (2% in 50 years). The weighted average results indicate residential wood structure has the highest damaged area. This observation is expected since 95% of the buildings in Montreal are residential buildings, and among these, wood single family houses are the most common ones (71%). In average, more than 9000 of single family buildings are estimated to suffer damages (6% of the total), followed by 6800 of multi-family residential buildings (5% of the total). In terms of structural type, 4% of the wood buildings (9600) and 10% of unreinforced masonry buildings (5900) are expected to be damaged. The average direct building related economic losses are estimated to be around 2.1 billion dollars. The estimated number of displaced households and people seeking short-term shelter are around 2500 and 1400 respectively. In terms of casualties, the estimated number of people injured varies between 350 and 500 depending on the time occurrence of the earthquake. The table 2 details the damage estimates divided in 4 degrees and separated by GMPEs.

Damages are mainly observed in the boroughs of Ville-Marie, Plateau Mont-Royal, Westmount, and Cote-Des-Neiges/ Notre-Dame-de-Grace(CDN/NDG) as shown in Figure 2 for an “average” scenario (aS) close to the weighted average results of all scenarios. 41 census tracts have the level of damage higher than 1 million square feet per square kilometre. Three fourth of these census tracts are located in Ville-Marie (12), Plateau Mont-Royal (11), and CDG/NDG(6).

Table 2 : Expected building damage for the 2% exceedance probability in 50 years seismic hazard. Number and percentage of damaged buildings, divided in four degrees, are given for the three GMPEs and the weighted average.

Building Damage / GMPEs	Slight (Number, %)		Moderate (Number, %)		Extensive (Number, %)		Complete (Number, %)	
AB95 Atkinson and Boore (1995)	28850	9.5	12160	3.9	3010	1	570	<1
AB06 Atkinson and Boore (2006)	9630	3.1	1740	<1	240	<1	40	<1
A08 Atkinson (2008)	840	<1	100	<1	140	<1	30	<1
Weighted average	12490	4.0	3930	1.3	910	<1	170	<1

A map of normalized total direct building economic losses for the average scenario is presented in Figure 1. Total loss includes loss due to structural damage, loss due to non-structural damage, building content damage, and business inventory loss. The highest loss by census tract occurs in Ville-Marie, Kirkland, and Point-Claire which is consistent with the direct physical damage result of the Figure 2. Building structural and non-structural losses are the largest contributors of all economic losses as they account for 65% of the total economic losses in average in all census tracts with damage. The rest of the economic losses are shared by content damage and inventory losses..

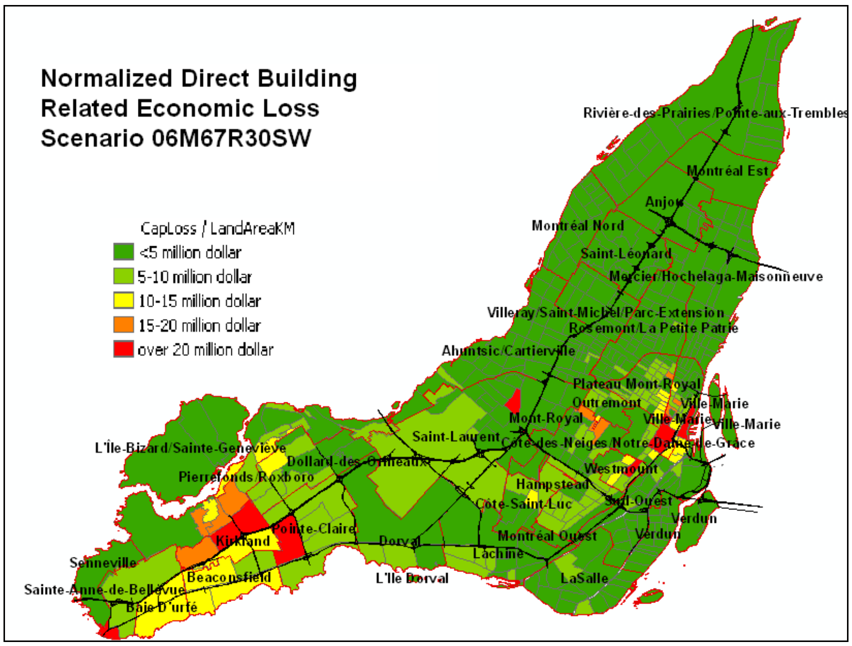

Figure 1: Normalized Direct Building Related Economic Loss in million CAD by census tract for an average Scenario.
The results are normalized by total land area of the census tract and aggregated to include all building types.

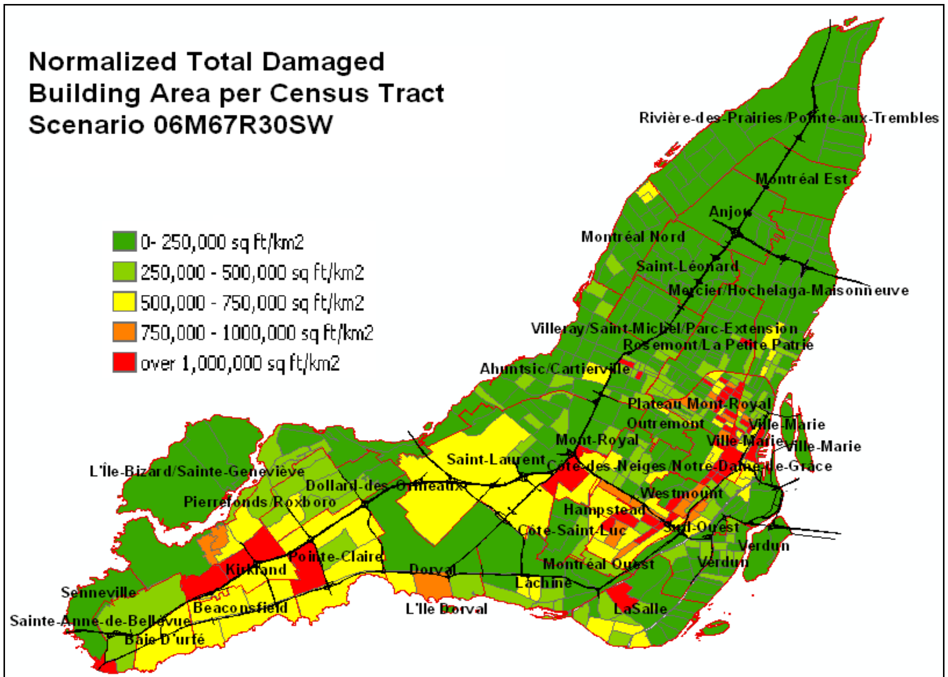

Figure 2: Normalized Total Damaged Building Area in ft^2/km^2 by Census Tract.
This map is based on the results of an average scenario and aggregated to include all building types and damage level. The results are normalized with respect to the total land area of the census tract.

Sensitivity analysis was performed across the 38 scenarios to investigate the most important input parameter that contributes to the uncertainties of results (Yu et al., 2013; Yu, 2011). Among all parameters, the choice of GMPEs is observed to be the most important parameter. Indeed, for a same magnitude-distance event, damage results vary up to a factor of 100 depending on the chosen GMPE; It is observed that AB95 generates the highest damages, followed by AB06, and AB08. Since earthquake loss estimation largely relays on the quality of input ground motion, it is beneficial to use a weighted average GMPEs approach to reduce this uncertainty in ground motion.

4 Conclusion

In this paper, we present the data and method used in earthquake loss estimate for the city of Montreal. It is found that the highest damage occurs in downtown Montreal due to its high building and population density. It is also found that the most important parameter in estimating damage using HAZUS is the choice of GMPE.

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