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THE USE OF HAZCAN TO ASSESS THE EARTHQUAKE RISK OF RESIDENTIAL BUILDINGS IN MONTREAL, CANADA.

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Abstract: Montreal is the second most vulnerable city for earthquakes, after Vancouver, considering the level of the seismic hazard level and the population. A study, supported by the Ministère de la Sécurité Publique du Québec, has been conducted to assess the losses to residential buildings for several earthquake scenarios. Population and building data have been collected for each of the 3'201 dissemination areas forming the Montreal Island. Inventory of the buildings in terms of occupancy and construction types uses mainly the information for about 350'000 buildings available in the 2016 municipal property roll of Montreal. Wood-frame buildings counts for 79% of the total, masonry for 18%, steel frame and reinforced concrete sharing the last 3%. Ground motion prediction equations for Eastern North America are applied for the different seismic scenarios taking into account microzonation in terms of V_{s30} derived soil classes. Depending on the scenario, damage ranges from 25 to 60% of the building stock, severely damaged and collapsed buildings representing 2 to 12% of the total. Non-structural damage accounts for 80% of the total losses. Generally, masonry houses built before the 20th century account for most of the damage as wood-frame structure perform best. The total losses vary between 1 and 12% of the portfolio for residential houses depending on the selected scenario. Preliminary estimates of the amount of debris generated by scenario earthquakes range from 0.6 to 6 million tons, with brick and wood debris representing approximately 60% of the total.

1 PROJECT OVERVIEW

The seismic risk analysis here described in this paper is a collaboration between the civil engineering department of the McGill University (Montreal, Canada) and the construction engineering department of the École de technologie supérieure (Montreal, Canada). It required a multidisciplinary team of seismologists, civil and construction engineers with an expertise in data management and GIS mapping. The project has been initiated at the request of the Ministère de la Sécurité publique of Quebec (Canada) to improve the knowledge of potential impacts of a large earthquake in the Montreal area in order to plan mitigation, preparedness and emergency response measures. The last damaging earthquake was reported in 1732 when the population and the extent of the city were considerably different from today's situation. More than 200 buildings were reported highly damaged and the epicentral intensity estimated to IX on the Modified Mercalli scale (MMI). Recent predictive analysis at different scales have nevertheless demonstrated that the risk remains relatively high and needs to be considered (e.g. Yu et al., 2016 ; BAC, 2013). The project is running for several years and the first phase focused on the effects of earthquake scenarios on residential building in Montreal. It is now extended to the greater Montreal area and will be further complemented by an analysis of the damage to lifelines.

The Canadian version of HAZUS, HazCan, has been used for the project (Ulmi et al., 2014). HAZUS was first developed for refined analysis of risk induced by different natural hazards and investigates damage to buildings, lifeline and human consequences (FEMA, 2003). The chart in Figure 1 summarizes the data needed to run HazCan. They concern demographic data, buildings by occupancy and construction types and soil conditions mapping, if needed. Output data relate to structural and non-structural damage and human losses.

The input data are derived from the demographic census of Statistic Canada which are available at the dissemination area (DA) scale delimiting area of about 700 people and 200 buildings. Montreal is divided in 3'201 DA and counted about 1.94 million of people in 2016. For each DA, people have been distributed into a set of socio-economical parameters such as the age, the sex, the incomes as requested by the HazCan format. The 2016 municipal roll of Montreal provided information on individual houses such as the number of floors, dwellings, the year of construction and the estimated value. The inventory of buildings by occupancy types have been derived from the latter dataset and complemented by literature, use of street map viewer and field investigation to validate hypothesis. A specific research was conducted on old masonry buildings downtown Montreal.

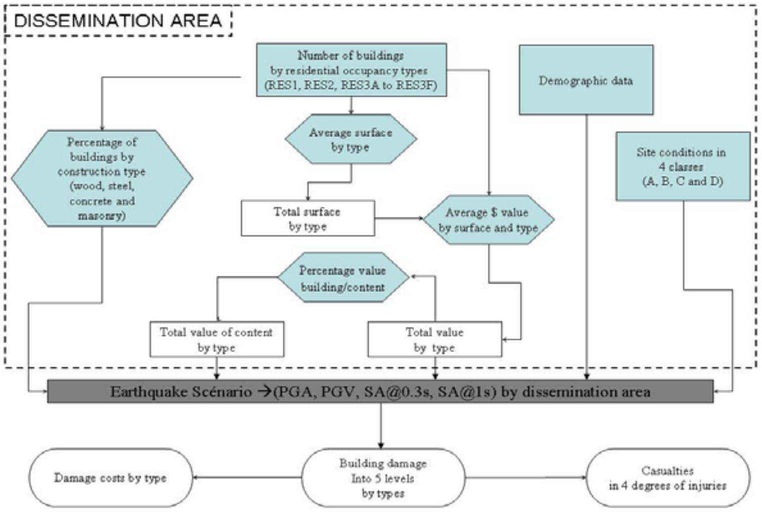

Figure 1. Data inventory in HazCan. Boxes filled in blue are the collected data. Unfilled ones are the derived and output data.

2 POPULATION AND BUILDING INVENTORY

Population data collected at the DA level were grouped by sex, age (<16 yr., 16-65 yr., >65 yr.) and by ethnic origin. They were complemented by the number of dwellings by incomes brackets. Most of the data are from the 2016 census and, when not available, were extrapolated from 2006 and 2011 census. The occupancy ratio during the daytime and nighttime is derived from daily commute studies.

Building inventory follows the HAZUS classifications for both the occupancy and construction types (FEMA, 2003). Due to limited time, attribution of structural type was based on the geographical location of the building, the year of construction and the number of floors; three information directly available from the assessment roll dataset. The city of Montreal has grown around the old city and the building characteristics evolved with architectural trends, seismic codes and urban land uses. A comprehensive literature analysis on residential architecture and building engineering practices helped to perform this classification. The graph of the Figure 2 show the distribution of the buildings into occupancy types based on a set of 349'549 residential buildings. Half of the buildings were built prior to seismic code while single family houses represent 56% of the total and duplex 23%. The map of the Figure 2 shows the distribution of the buildings by construction types for each DA. Most of the buildings are wood frame (79%) and unreinforced masonry ranks second (18%). Each pie chart in the map corresponds to a dissemination area.

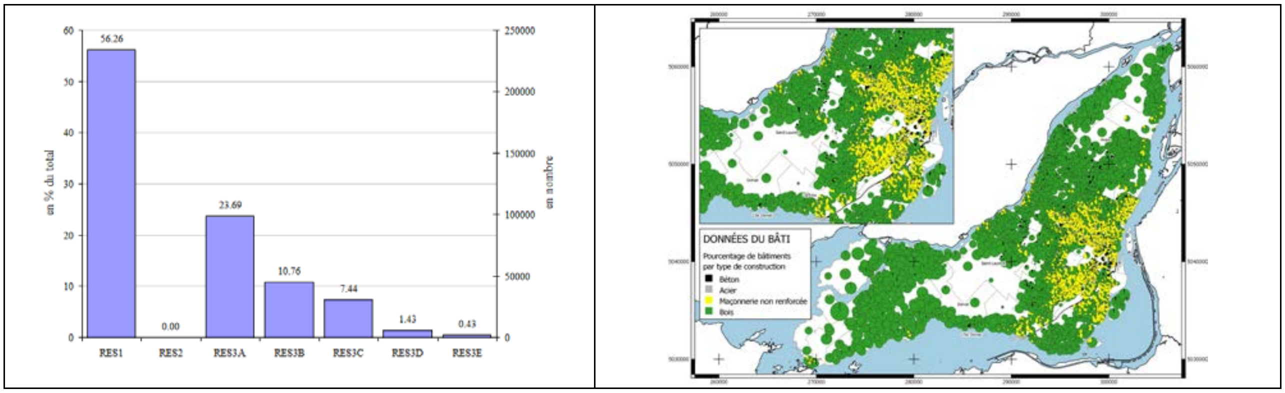

Figure 2. Distribution of building by occupancy types (left) and by construction types (right).
RES1: single-family house, RES3A: duplex, RES3B: 3-4 dwellings, RES3C: 5-9, RES3D: 10-19 and RES3E: 20-49.
Each pie chart in the map corresponds to a dissemination area. Green color is for wood frame house, yellow for unreinforced masonry, gray for steel frame and black for concrete frame building.

3 DAMAGE FOR SPECIFIC EARTHQUAKE SCENARIOS

The risk analysis has been performed based on six deterministic scenarios with epicentres located in different zones around Montreal (Rosset et al., 2019; Chouinard et al., 2018). They combine the information on low magnitude seismic activity (Ghofrani et al., 2015) and the seismic disaggregation calculated for a return period of 2475 yr. (Halchuck et al., 2015). Four of the scenarios are located in areas that are recently more active than the average background rate (SC1 to SC4). The magnitude for these events is set at M6.7 which is the most significant contribution to seismic hazards at distance between 50 and 65 km for design events. Scenario SC5 represents a maximum expected event centred in Montreal with a magnitude of 5.8 and corresponds to the estimated magnitude of the 1732 event with an estimated MMI of IX. The last scenario (SC6) corresponds to an event 30 km south of Montreal with a magnitude of 6.1, which contributes 8% to the design level event. The depth of the source is fixed at 10 km. The Central Eastern US composite attenuation equation proposed in HazCan is used to calculate the shakemaps. The microzonation in terms of NBCC2015 site classes is provided by previous works (Rosset et al. , 2015; Rosset and Chouinard, 2009).

The Table 1 shows the calculated damage (in %) for the different scenarios grouped in 5 degrees and by occupancy types. Values from the scenarios SC1 to SC4 are averaged in order to consider the overall influence of the location of the different sources. The scenarios SC5 and SC6 are considered separately.

Table 1. Building damage distribution (in %) by occupancy types and scenarios.

Scenario	Occupancy type	None	Slight	Moderate	Extensive	Complete	Number of buildings
SC1 SC2 SC3 SC4	Single family (average)	85.1	11.4	3.1	0.4	<0.1	196,640
	Other residential (average)	78.0	14.3	6.2	1.3	<0.1	153,676
SC6	Single family	80.3	13.8	4.9	0.8	0.2	196,640
	Other residential	72.3	17.0	8.2	2.0	0.5	153,676
SC5	Single family	48.0	28.4	17.9	4.5	1.3	196,640
	Other residential	23.5	27.8	28.7	13.1	6.9	153,676

In Table 1, the worst scenario SC5, located in the center of Montreal, gives relatively high percentage of complete damage especially for building with more than 1 dwelling which are predominantly unreinforced masonry ones. Results also show a large proportion of steel and concrete frame buildings in extensive and complete damage states. However, these construction types represent a small number of buildings in the inventory and therefore a small contribution to total losses. When considering the overall damage distribution, slight and moderate damage affect 22% of the buildings for scenario SC6, 51% for SC5, and from 13 to 21% for the other scenarios. Extensive and complete damage represent 2% for scenario SC6, 12% for scenario SC5 and 1 to 2 % for the other ones. The cost of structural and non-structural damage varies from 0.9 to 11 billions Can$ depending on the scenarios, the non-structural damage counting for approximately 4/5 of the total cost. It is 1 to 12% of the total estimated portfolio of around Can$87 billions excluding contents The quantity of debris ranges from 600 to 6000 kilo-tons, wood and brick debris being twice steel and concrete ones.

4 INNOVATIONS AND LESSONS LEARNED

The use of HazCan for seismic risk analysis is unique in Eastern Canada. The adopted resolution at the DA scale was possible thanks to the data available on Statistic Canada and shared with us by the city of Montreal and the Ministère de la Sécurité Publique of Quebec. This project is conducted by a multidisciplinary team which help to embrace all topics related to the risk analysis and particularly the engineering aspects. A particular effort is done to better understand the seismic resistance of wood-frame in the context of Montreal. Several issues need to be improved in the next steps of the project:
1- The damage results for steel and concrete buildings are overestimated and the performance of the fragility data included in HazCan needs to be checked with data specific to the Montreal region.
2- Considering the large number of wood buildings, fragility data need to be ascertained.
3- The attenuation equations included by default in HazCan seems to overestimate the ground motion at short distance from the source. The effect on the final results need to be investigated.
3- The calculation of non-structural damage such as the fall of chimneys and cladding needs to be improved in HazCan since this is typical damage which could be observed during large earthquake as attested during the 1949 Cornwall and 2008 Saguenay M5.8 earthquakes.

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