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Could Montreal residential buildings suffer important losses in case of major earthquakes?

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ABSTRACT

Recent insurance reports on seismic risk in Quebec suggest the potential for substantial losses in case of a major earthquake. A detailed analysis is performed in Montreal for residential buildings using HazCan, the Canadian version of HazUS. An inventory of population and existing building stock is developed at the scale of census dissemination areas. Wood frame structures constitute 80% of the total square footage, while unreinforced masonry buildings account for 18%. Single-family houses represent more than 36% of the square footage, followed by duplex (23%), triplex (13%) and multi-storey buildings (28%). The total value of the residential building stock is estimated around 87 billion CAD excluding contents. Six different seismic scenarios are considered which account for potential rupture sources identified through disaggregation of the seismic hazard curve and from the analysis of recent seismicity. Ground motion prediction equations for Eastern North America (CEUS, 2008) are used taking into account microzonation data in terms of Vs_{30} derived soil classes.

Depending on the scenario, property damage ranges from 25 to 60% of the total building stock and from 2 to 12% for severely damaged and collapsed buildings. Non-structural damage accounts for 80% of the total losses. Generally, wood frame structures perform best while masonry houses built before the 20th century account for most of the damage. The total losses vary between 1 and 12% of the value of the portfolio of residential houses (2016 value) depending on the selected scenario. Preliminary estimates of the amount of debris generated by scenario earthquakes range between 0.6 to 6 million tons, with brick and wood debris representing approximately 60% of the total.

The analysis was conducted in collaboration with the city of Montreal (Direction de la sécurité civile de Montréal) and the provincial government of Quebec (Ministère de la Sécurité publique) to identify high risk areas and to improve seismic preparedness and emergency planning.

Keywords: Earthquake, Risk, Montreal, Residential, Losses

INTRODUCTION

Recent studies from industry, government and universities recognize the potential for damaging earthquakes in Eastern Canada and particularly in the urbanized region of Montreal [1-3]. Montreal is the second most populous metropolitan centre in Canada with more than 1.9 million inhabitants (2016 census). It was initially settled in the 17th century and thus comprises a wide range of types of buildings and a large proportion that were constructed prior to the introduction of modern seismic design codes. In addition, a significant portion of the city was built on soft soil deposits in proximity to the Saint-Lawrence River, which are known to increase the amplitude of seismic waves. A seismic microzonation of Montreal and surrounding municipalities was produced to identify these zones of potential wave amplification (e.g. [4-6]).

Historical records indicate that the Montreal area is a region of moderate seismic activity. Only 5 historical events have been reported with Modified Mercalli Intensities (MMI) greater than VI during the last 350 years. The National Building Code of Canada ([7]) specifies a horizontal PGA of 0.379 g with a probability of exceedance of 2% in 50 years.

A previous seismic risk analysis for residential buildings in Montreal was performed at the level of census tracts ([8]). The present study presents an update of this study at a more detailed spatial scale with an updated data set that integrates the most recent information on the seismic microzonation. HazCan [9], the Canadian version of HAZUS [10], is used to perform the analyses for a set of deterministic scenarios. Results are presented for total structural and non-structural damages and costs.

ELABORATION OF THE DATABASE

Demographic and building databases

The resolution of the analysis is at the dissemination area (DA) level, which is an area comprised of one or more adjoining dissemination blocks, each with a population of 400 to 700 persons as defined by Statistic Canada. Montreal is comprised of a total of 3,201 DAs (Figure 1). Population data was obtained from the 2016 census of Statistic Canada. A previous study on home-to-work commuting was used to derive distributions of daytime and nighttime (Figure 1) populations. Other socioeconomic parameters such as age distribution, incomes, ethnic origin, etc. were compiled for the analysis by HazCan.

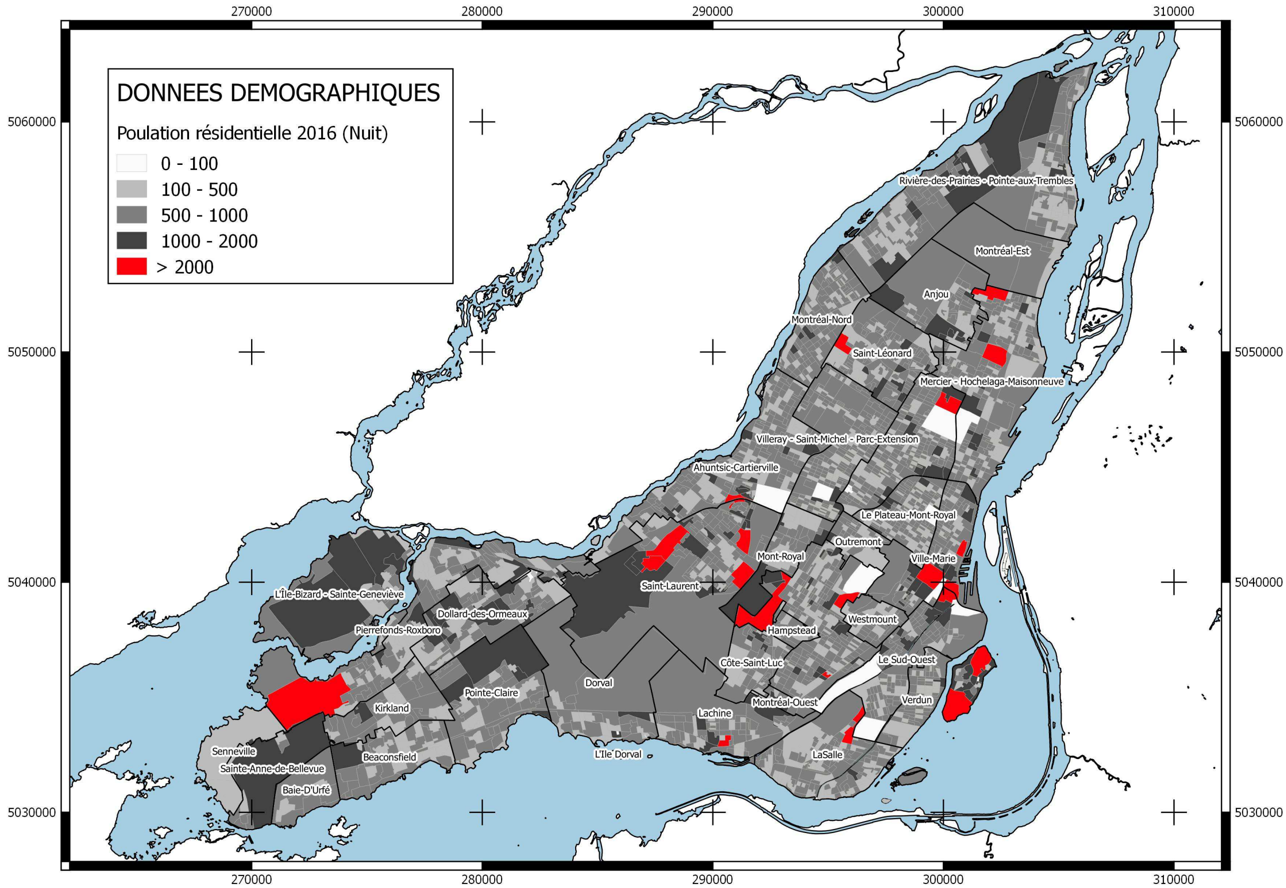

Figure 1. Division of Montreal into dissemination areas (DA). The shading shows the population by DA during the night as provided by Statistic Canada (2016). Limits of the municipalities are drawn and their name is indicated in bold.

The building portfolio was compiled using the evaluation role of Montreal of 2014 for approximately 350,000 buildings. Information from the role includes the year of construction, the number and total area of floors and the monetary value of the building. This information was cross-referenced with the location of buildings and the historical evolution of construction practices and standards to define the distribution of building as a function of type of construction and occupancy according to the HAZUS classification.

Figure 2a shows the distribution of buildings by occupancy type for each DA. Single-family dwellings represent 56% of the total, 24% for duplex, 11% for triplex, and 9% for buildings with more than 5 dwellings. Wood frame buildings represent 79% of the buildings and unreinforced masonry buildings with fewer than 3 floors, 11% (Figure 2b). Only a few reinforced concrete and steel structures are listed for residential construction [11].

The evaluation role was also used to obtain the average square footage and the monetary value by square footage per occupancy and construction types. The total value of residential buildings excluding contents is estimated approximately to 87 billion CAD.

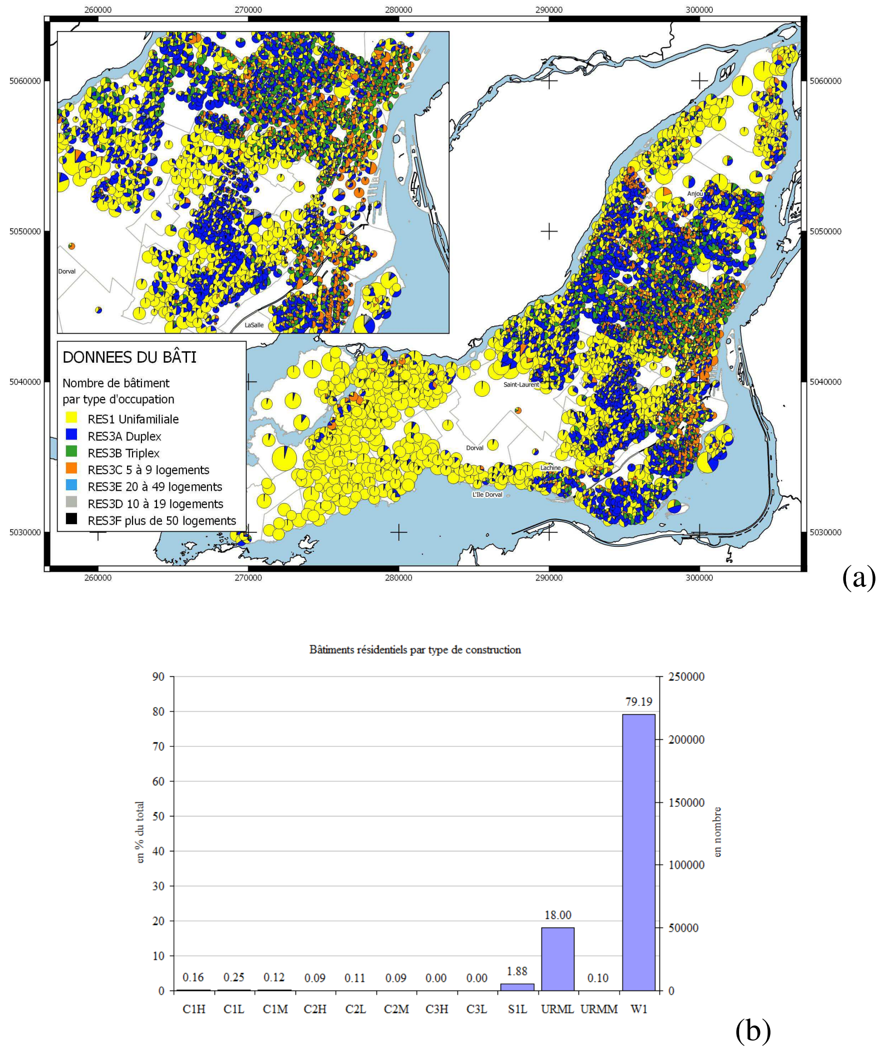

Figure 2. Distribution of building (a) into occupancy types by DA and (b) into construction types.
(a) Each pie chart represents a dissemination area and shows the distribution of buildings into occupancy types (number of dwellings). RES1; single family, RES3A; duplex, RES3B; Triplex, RES3C; 5-9 dwellings, RES3D; 10-19 dwellings, RES3E; 20-49 dwellings, RES3F; more than 50 dwellings.
(b) Overall distribution of building into construction types. W1; wood frame, URML; unreinforced masonry, S1; Steel, C for reinforced. L is for Low-rise 1-3 floors, M; mid-rise 4-7 floors and H; high-rise.

Seismic scenarios and soil conditions data

In previous studies, a seismic zonation of Montreal was developed as a function of site predominant frequency of resonance and Vs_{30} (e.g. [4-6]). This zonation was used as additional input for ground motion calculations in HazCan.

Earthquake scenarios were also developed by considering probabilistic hazard deaggregation [12] and recent background seismicity rates and felt observations around Montreal [13]. Four of the scenarios are located in areas that are recently more active than the average background rate (SC1 to SC4 in Figure 3). Scenario SC1 corresponds to the location of the 2010 M5.0 Gatineau earthquake [14]. Scenarios SC2 to SC4 are moderately intense events in locations with limited historical data northeast and southeast of the city. The magnitude for these events is set at M6.7 since events at epicentral distances between 50 to 65km contribute significantly to seismic hazards for design events with a return period of 2475 years. Scenario SC5 represents a maximum expected event centered in Montreal with a magnitude of 5.8 and corresponds to the estimated magnitude of the 1732 event with an 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.

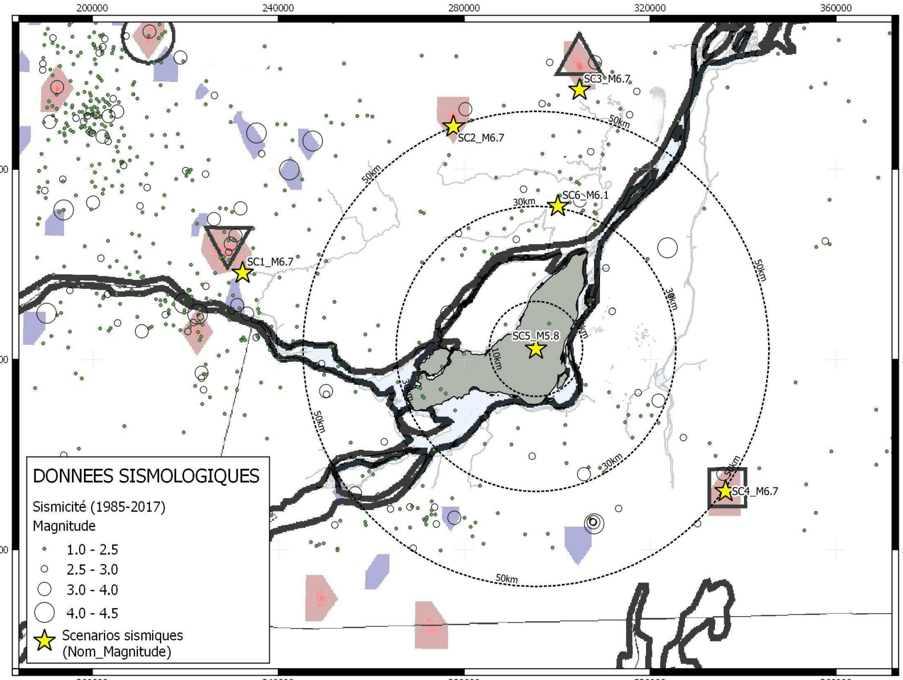

Figure 3. Earthquake scenarios SC1 to SC6. Scenarios and their associated magnitude M are shown by yellow stars. Recorded earthquakes since 1985 are indicated by circles. Areas that are more active than the average background rate (seismic activation) are shown in red, those that are less active than the average background rate (seismic quiescence) are shown in blue [13].

A composite ground motion prediction equation adopted for the Central and Eastern US in HAZUS ([10]) is used to obtain the Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) and Spectral Acceleration (SA) at 0.3 and 1s for each scenario. Figure 4 illustrates the PGA calculated for scenario SC5 of M5.8 located in the centre of Montreal.

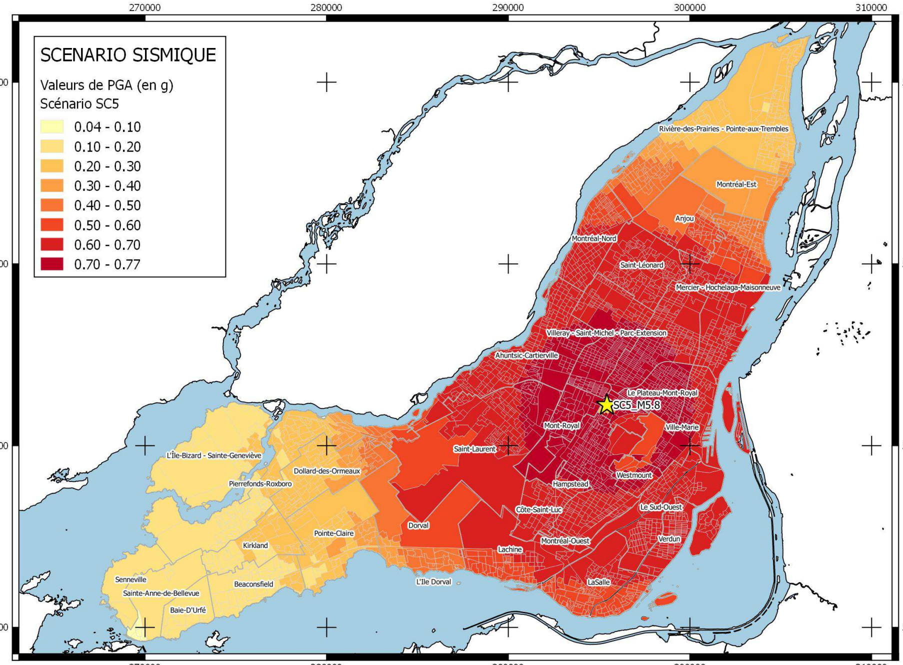

Figure 4. PGA field calculated or the scenario SC5 (in g=9.81 m/s^2). The epicentre is located by a yellow star. Calculation of PGA considers site class amplification factors from the microzonation map.

RESULTS OF SEISMIC RISK ANALYSIS USING HAZCAN

Damage to buildings

Damage to buildings is divided in 5 levels; None, Slight, Moderate, Extensive and Complete. Table 1 summarizes the main results for the different scenarios.

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

The distributions of damage by construction type for each scenario are presented in Figure 5. Scenario SC5 located in the centre of the city is obviously the most damaging. One can notice the large proportion of masonry (M) buildings with extensive and complete damage states compared to wood frame structures for all scenarios. 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, extensive and complete damage represents 2% for scenario SC6, 12% for scenario SC5 and 1-2 % for the other ones. Slight and moderate damage affect 22% of the buildings for scenario SC6, 51% for SC5, and from 13 to 21% for the other scenarios.

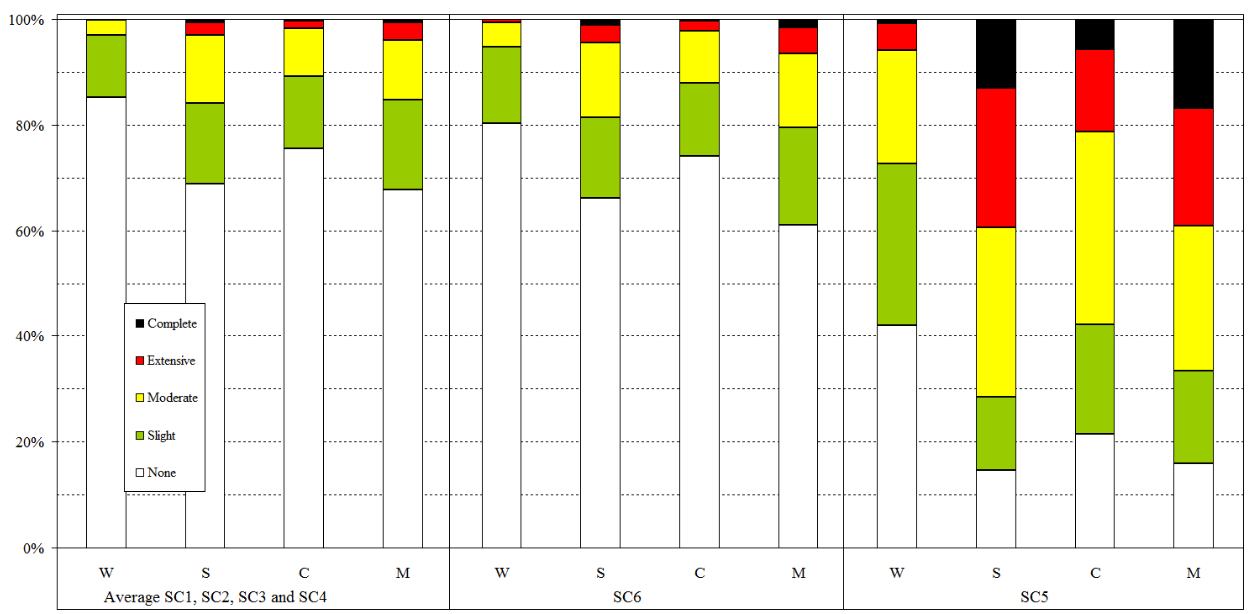

Figure 5. Damage distribution construction types for the different scenarios. Damage is divided in 5 levels from no damage to complete. The percentage of damage into these 5 levels is averaged for the scenarios SC1 to SC4. The scenarios SC5 and SC6 are presented individually. W: Wood frame; S: Steel frame; C: reinforced concrete; M: Masonry.

Economic losses

Economic losses are estimated for both structural and non-structural damages. Non-structural damage accounts for 80% of the total losses. The good performance of wood frame structures, and their large number, counterbalance for the poor behavior of masonry buildings built before the 20th century. The total losses vary between 1 to 12% of the value of the portfolio of residential houses (2016 value) depending on the selected scenario (Table 2).

Table 2. Economic losses by construction types and scenarios (in % of the total). .

Scenario	Occupancy type	Wood	Steel	Concrete	Masonry	Total
SC1 SC2 SC3 SC4	Structural (average)	0.1	0.4	0.6	0.7	0.2
	Non-Structural (average)	0.6	1.7	1.5	1.8	0.9
SC6	Structural	0.2	0.5	0.6	1.0	0.3
	Non-Structural	1.2	2.2	1.6	3.3	1.5
SC5	Structural	1.1	3.5	4.2	5.4	1.9
	Non-Structural	7.5	15.8	15.6	25.0	10.7
	Economic value (M$)	69,620	1,982	1,396	14,303	87,302

Estimate of debris volume

A first estimate of the amount of debris which could be generated by building damage is summarized in Table 3. One can notice that 60% of debris are from wood and brick. For a truck with a loading capacity of 25 tons, the estimated truck trips exceed 25,000.

Table 3. Estimation of the amount of debris by types (in thousands of tons)

Scenario	Wood and brick	Steel and concrete	Total
SC1, SC2, SC3, SC4 (average)	446	208	654
SC6	651	323	974
SC5	3,312	2,694	6,007

CONCLUSIONS

This seismic risk analysis conducted in Montreal for residential buildings at the scale of dissemination areas is an important step to better understand what could be the consequences of a large earthquake in the second most populous urban area in Canada.

Population data collected from Statistic Canada for 2016, and a inventory of about 350,000 residential buildings, were used to create a dataset of building distribution into occupancy and construction types following the HAZUS classification. It shows a predominance of wood frame structures (79%) and single-family houses (56%). Masonry structures complete the building stock with 11%. Based on the data of the evaluation role, the value of the building stock has been estimated around 87 billion CAD excluding its content.

The six different scenarios that were proposed consider potential earthquake sources around Montreal including a repeat of the M5.8 1732 earthquake of estimated intensity of IX on the MMI scale.

The level of damage to buildings remains relatively low since extensive damage accounts for 8% of the building stock for the maximum credible scenario and 1% for the other scenarios, and 17 to 51% of the buildings could be affected by moderate to slight damage. The estimated costs of structural and non-structural damage represent 1 to 12 % of the estimated building portfolio depending on the selected scenario. Our analysis also points out the importance to consider the management of debris after the earthquake since their amount is evaluated around 0.6 to 6 million tons depending on the scenario, mainly from woods and bricks.

The results of the analysis have been shared with the Direction de la sécurité civile de Montréal and Ministère de la Sécurité publique du Québec with the intention to help them for future mitigation planning and preparedness.

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