EARTHQUAKE LOSS ESTIMATION DATA COLLECTION AND PREPARATION FOR URBAN DISASTER MANAGEMENT: A CASE STUDY FROM THE CITY OF OTTAWA, CANADA

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RÉSUMÉ
Cet article présente l'exemple du centre-ville d'Ottawa, Canada. L'objectif est d'identifier les endroits les plus vulnérables, tant au niveau physique que social, lors d'un tremblement de terre. Un inventaire détaillé de l'infrastructure, incluant les édifices, les structures et les réseaux essentiels, a été compilé. Pour pouvoir évaluer les pertes sociales immédiates comme les morts et les blessés, il a fallu utiliser de l'information recueillie lors du recensement. Des études de microzonation ont été menées et ont été classifiées selon les catégories de réponse du sol définies par NEHRP à partir de mesures de V_{s30}. Les paramètres de mouvement du sol utilisés sont les valeurs d'aléa sismique ayant une probabilité de dépassement de 2% en 50 ans, provenant du Code national du bâtiment - Canada 2005. Ils comprennent l'accélération maximale et l'accélération spectrale à 0,3 et 1,0 seconde. Toutes les données recueillies ont été intégrées dans un groupe de bases de données standard pour systèmes d'information géographique, compatibles avec le logiciel HAZUS-MH.

ABSTRACT
This paper focuses on a case study of downtown Ottawa, Canada. The objective is to identify areas most physically and socially vulnerable to an earthquake event. A detailed infrastructure inventory, including buildings, structures and lifelines was completed. Key building inventory inputs include information on building type, occupancy class and square footage. Estimations on immediate social losses such as casualties required census information. Microzonation studies were conducted and classified into NEHRP site categories based on average V_{s30} measurements. Ground motion parameters were seismic hazard values extracted from the 2005 NBCC for expected motions at a 2% exceedence probability in 50 years, including PGA and response spectra (SA at 0.3s and 1.0s) values. All collected data was assembled into a set of standard GIS geodatabases that are compatible with the HAZUS-MH software.

1. INTRODUCTION

Global urbanization has increased significantly in recent decades. In 2001, it was estimated that 50% of the world's population resided in urban centres, as opposed to 18% in the 1950s (Wenzel *et al.* 2007). Urban centres are generally academic, economic and political hubs. Due to this centralization of culture, the effects of disturbances, including natural hazards, may affect entire regions or countries. Bilham (1988) estimated that 40% of all major urban centres are located within 200 km of a tectonic plate boundary or in a region that has historically experienced a damaging earthquake. Dense population networks, complex and aged infrastructure, dependence on lifelines and limited preparedness programs are all factors which contribute to urban centre vulnerability (Wenzel *et al.* 2007). On the other hand, there has been an encouraging reduction of physical, social and economical losses from natural hazards in developed countries for several reasons including strict and enforced building codes, incentives to upgrade existing buildings and the development of natural hazard insurance (Spence, 2004). In the case of urban centres with older infrastructure, this points to the potential to reduce risk through retrofit programs. An accurate assessment of the risk is a necessary first step to justifying and then implementing risk-reduction measures.

Urban centres tend to focus on post-disaster responses which do not reduce the inherent risks (Wenzel *et al.* 2007). Mitigation, on the other hand, is a cost effective approach to better the overall effectiveness of reducing losses associated with natural hazards. Mitigation involves the support and participation of several stakeholders including academia. Often a breakdown in communication exists between academia and policy makers (Wenzel *et al.* 2007); however, this is gradually being rectified with the introduction of user-friendly GIS software packages similar to HAZUS (HAZards United States). HAZUS is an earthquake loss estimation program developed by FEMA (Federal Emergency Management Agency) through the National Institute of Building Sciences, but has grown to become a multi-hazard loss estimation program applicable to the United States. HAZUS methodologies have also been used worldwide, for example HAZ-Taiwan was a project developed in 1998 to promote research in seismic hazard analysis, structural damage assessment and socio-economic loss estimations in Taiwan (Yeh *et al.* 2006).

GIS software packages are not only user-friendly but also save valuable time and effort when managing geographically-sensitive information and databases (*e.g.* Enomoto *et al.* 2007). Several user-friendly loss estimation

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software packages can be applied in mitigation plan proposals and used immediately after a seismic event as decision-making support tool (Yeh *et al.* 2006). Therefore software packages like HAZUS are powerful tools which link academia, policy and land-use, and are important stepping stones in disaster management.

1.1 Seismic Hazard in Ottawa, Canada

Eastern Canada is located in an intraplate setting within the North American plate, where most large earthquakes occur on or near Paleozoic or younger rifts where the continent has been most recently weakened (Adams, 1989a). Seismicity in eastern Canada is suggested to be associated with the reactivation of a Paleozoic rift system (Adams, 1989a). The Ottawa area is located within a portion of the failed rift system referred to as the Ottawa – Bonnechere Graben (Eyles, 2002). However, evidence also suggests that some earthquakes may be associated with postglacial faulting (Adams, 1989b) and isostatic rebound (Adams and Clague, 1993).

Eastern Canadian earthquakes pose significant hazard to dense population centres, as earthquakes in eastern North America shake a larger area due to lower attenuation (Adams, 1989a) from a relatively stable and unfractured crust (Atkinson, 1989), in comparison to western events. The largest reported historical earthquakes in the Ottawa region (within approximately 350 km) are the 1732 M_w5.8 Montreal earthquake, 1935 M_w6.2 Timiskaming earthquake, and the 1944 M_w5.6 Cornwall-Massena earthquake (where M_w is moment magnitude) (Lamontagne *et al.* 2007). All three of these large earthquakes were felt in the City of Ottawa (Lamontagne *et al.* 2007).

The Ottawa area is the most seismically active area in Ontario (Eyles, 2002). Aylsworth *et al.* (2000) presented evidence of massive paleo-landslides in the Ottawa area, approximately 4,550 and 7,060 years ago, that were triggered by "*two of the most geologically destructive earthquakes in eastern Canada.*" A study for the City of Ottawa reported that the second largest public safety threat was an earthquake (Adam, 2004). Additionally, Adams *et al.* (2002) in Adams and Halchuk (2004) ranked Ottawa third in the urban centres most at seismic risk within Canada, after the cities of Vancouver and Montreal.

The primary objective of this paper is to outline the steps needed in data collection and preparation to identify areas most physically and socially vulnerable to earthquake ground shaking. The earthquake ground shaking for the evaluation is the ground-motion spectrum given in the 2005 National Building Code of Canada, representing motions with a 2% chance of being exceeded in 50 years. The paper presents a case study of downtown Ottawa, Canada, using the HAZUS-MH software tool. The focus is on data collection and inventory requirements for the assessment.

1.2 Study Area

The study area consists of two full census tracts or 10 dissemination areas (a smaller subdivision of census tracts), located in downtown Ottawa, which span west-east from Bronson Avenue to Cumberland Street, and north-south from Guigues Avenue and the Ottawa River to Gloucester Street, refer to Figure 1.

The study area is underlain by Paleozoic sedimentary rocks, predominantly limestone and shale, at a depth that ranges

Figure 1. Map of the study area located in downtown Ottawa, Canada. (Data sources: Statistics Canada, NRCan, and the City of Ottawa)

from less than 1 m to 40 m. Drift deposits consist predominantly of glacial till and post-glacial offshore marine sediments (consisting of erosional terraces and silt/clay deposits). Their respective ages were determined by the use of a geological map of the Ottawa area (Richard, 1978), and supplementary literature (*e.g.* Holman *et al.* 1997). Borehole logs from NRCan (Natural Resources Canada) reveal numerous pockets of artificial fill ranging from sand and gravel to ashes and organic material. An important addition to the original NRCan geological unit layer is the uncompacted fill located under Confederation Park and extending across the Rideau Canal to Nicholas Street. In the early 1900s, a lay-over for ships existed in this area but it was filled in the mid-1910s (Nagy, 1974).

The study area is of strategic importance as several key regional, national and international buildings are located here, including City Hall, various federal government agencies, Parliament Hill, and several embassies; thus the study area is of prime interest for emergency managers, planners and engineers.

2. DATA COLLECTION AND ANALYSIS

2.1 General Building Inventory

The collection of the general building inventory was time-consuming and expensive; however, these data are essential in the execution of model loss estimations. A sidewalk survey was conducted where building type, occupancy class, number of stories and other information was collected and digitally catalogued. In our study area, a total of 597 buildings were inventoried. The list was dominated by unreinforced masonry (40%) and concrete (35%) building types, and commercial (60%) and residential (30%) occupancy classes. Square footage was calculated using both building footprints on high resolution aerial photographs and information collected in the field. The cost of each building (not including content cost) was calculated per square foot based on a default table of subdivided occupancy classes presented in the HAZUS technical manual. These values should be considered a minimal replacement cost, as all buildings were treated without consideration of their intrinsic or downtown real estate market values.

Additional information on structure and buildings of interest was collected. A structure inventory of highway bridges was conducted where the bridge width, length, number of spans, and bridge class were recorded. Buildings of interest in the study area included essential facilities (schools, medical clinics, and emergency management buildings), utilities (electrical plants, communication facilities and transmitters) and high potential loss facilities (military installations).

2.2 Demographics

Modeling casualties requires specific information on demographics, in this case the residential and commercial population distribution at three time periods during the day; daytime, nighttime and commuting or 2pm, 2am and 5pm, respectively. Refer to Table 1.

Table 1 – Residential and working populations at three different times during the day. (Source: City of Ottawa)

Time	Census Tract	Population Type		Total
		Residential	Commercial	
2 AM	East	2,238	414	2,652
	West	3,718	214	3,935
2 PM	East	224	10,439	10,663
	West	372	65,688	66,060
5 PM	East	448	10,003	10,451
	West	744	18,003	18,747

2.3 Potential Earth Science Hazards (PESH)

HAZUS identifies four PESH requirements to model earthquake loss estimations: soil classification, liquefaction susceptibility, landslide susceptibility and water depth. The aforementioned PESH requirements are site specific and are not uniform across the entire study area, which plays an important role in identifying regions of increased vulnerability.

2.3.1 Soil Classification

Microzonation studies provide a detailed map of ground conditions within a small area, such as a city. These measurements are useful for seismic hazard and risk mitigation. The sites are typically described in the context of the National Earthquake Hazards Reduction Program classifications (NEHRP), which have been recently adopted by the 2005 National Building Code of Canada (NBCC). NEHRP soil classes are based on a measured travel-time-weighted average of shear wave velocity to a depth of 30 metres (V_{s30}). The use of V_{s30} as a soil response parameter is a simplification, as in fact the amplification depends on both the soil stiffness and its thickness (Motazedian and Hunter, 2007). The NEHRP site classification assigns each site a class, from A (hard rock) to F (problematic soils), as shown in Table 2.

Table 2. NEHRP site classes (NIBS, 2006). V_{s30} is measured in m/s.

Site Class	Soil Profile Name	V_{s30}
A	Hard rock	1500 < Vs
B	Rock	760 < Vs < 1500
C	Very dense soil and soft rock	360 < Vs < 760
D	Stiff soil	180 < Vs < 360
E	Soft soils	< 180
F	Problematic soils	Site specific evaluation

V_{s30} can be determined by several methods, including borehole shear wave velocity measurements (*e.g.* Hunter *et al.* 2007), shear wave reflection Landstreamer technology (*e.g.* Pugin *et al.* 2007), and seismic reflection/refraction surveys using a hammer with an electronic trigger (*e.g.* Motazedian and Hunter, 2007).

Seismic reflection/refraction data in the study area was acquired by using a non-invasive seismic array geometry developed by Hunter and Motazedian (2006). All sites experienced significant cultural noise; therefore each shot was stacked 8 times to enhance the signal-to-noise ratio.

To determine V_{s30} and drift depth, data was interpreted using a combination of methods used by Hunter and Motazedian (2006) and the Geological Survey of Canada (GSC) (H. Crow, personal communication, 2007). First, data was plotted to determine best-fit linear trendlines and their related equations, as shown in Figure 2. The slope of each trendline was inverted to determine the shear wave velocity of that particular layer.

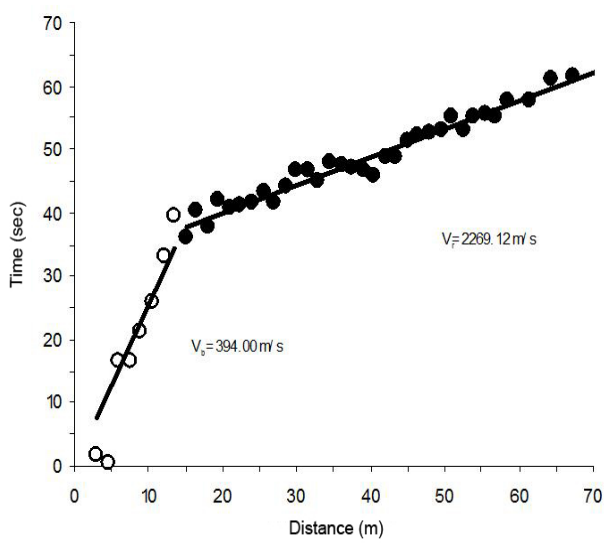

Figure 2. Interpreted traveltimes and resulting shear-wave velocities at site 366 (Supreme Court of Canada).

The results of V_s for both layers were input into a BASIC program called "refract' created by Dr. Jim Hunter of the GSC. The output of this program provides the drift thickness, the depth of the interface between the surface layer and the bedrock. These results were then input into an Excel spreadsheet created by Heather Crow of the GSC to determine the V_{s30} in 5 m intervals to a depth of 30 m.

All survey sites in the study area were determined to be NEHRP class B with the exception of Confederation Park which was class C. NEHRP classes B to C cover very dense soil to rock are considered to be a stable soil classification, as these classes tend to be less susceptible to ground deformations. Many other areas of Ottawa, outside the downtown core, are characterized by much softer deposits (Hunter and Motazedian, 2006; Hunter *et al.* 2007).

2.3.2 Ground Motion Parameters

The ground-motion parameters used for the assessments in this paper included PSA (pseudo spectral acceleration) and PGA (peak ground acceleration) as presented in Adams and Halchuk (2003) and used in the 2005 edition of the National Building Code of Canada. The parameters are expected median ground motions at a probability level of 2% in 50 years; they are listed in Table 3. There a variety of options in HAZUS-MH to model ground motions within a study area including historical earthquakes, user supplied information and probabilistic hazard selections. User supplied information was chosen for this paper due to both a lack of Canadian historical earthquake databases and 2005 NBCC probabilistic ground motions in the HAZUS software program.

In order to determine the approximate hypocentral distance from Ottawa for a given magnitude, we used Mw6.5 ground-motion relations presented in Atkinson and Boore (1995); these relations were chosen for consistency with those used in the hazard calculations. The parameters listed in Table 3 are given for Site Class C while the ground-motion relations in Atkinson and Boore (1995) are given for Site Class A. Therefore, a conversion factor must be applied to convert the ground motions from Site Class C to A. The conversion factors used for this purpose are those provided in the NBCC, as given by Finn and Wightman (2003). This ensures internal consistency, as the HAZUS methodology uses these same factors. The estimated Class A motions based on these factors were used in conjunction with the Atkinson and Boore (1995) look-up tables (AB95) to obtain the appropriate hypocentral distance of a magnitude 6.5 earthquake, considering that high-frequency motions are dominated by moderate events, while long-period motions are dominated by large events. Figure 3 shows the NBCC spectrum for Ottawa (reduced to values for NERHP A) in comparison to the selected M_w6.5 at 20 km.

Table 3. Summary of ground motion parameters for Ottawa, ON, presented in Adams and Halchuk (2003) for site class C; equivalent values for class A are also shown, based on factors of Finn and Wightman (2003). SA and PGA are measured in g.

Class	Latitude	Longitude	Sa(0.2s)	Sa(0.5s)	Sa(1.0s)	Sa(2.0s)	PGA
Class C	45.27	-75.75	0.66	0.32	0.13	0.044	0.42
Class A			0.528	0.192	0.065	0.0176	0.294

Once the hypocentral distance was established, appropriate geographic coordinates for the scenario event can be entered into a loss estimation software program like HAZUS to determine the expected ground motions within the study area.

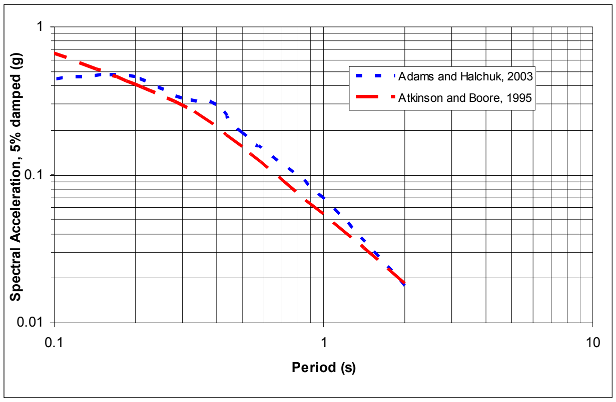

Figure 3. UHS (uniform hazard spectra) for Ottawa (2%/50years) from Adams and Halchuk (2003) compared to AB95 (Atkinson and Boore, 1995) scenario M_w6.5 at 20 km hypocentral distance beginning at 0.1 s.

2.3.3 Liquefaction Susceptibility

Intense ground shaking can cause various types of ground failure, including liquefaction. Liquefaction is the process by which water-saturated granular material loses its strength, as earthquake shaking causes the pore water pressure to exceed the confining pressure. Liquefaction susceptibility refers to the relative ease of a particular saturated geological unit to liquefy under intense shaking and is assigned qualifiers from "*very low*" to "*very high*" (Youd and Perkins, 1978). The main factors affecting liquefaction are: (1) grain size, where clean sand (that is, sand with no clay, silt or bonding material) and sensitive clays (that is, clay that can rapidly lose their shear strength when disturbed) tend to be most susceptible to liquefaction; (2) relative density, where the arrangement or packing of sediments can dramatically change the susceptibility and is heavily influenced by depositional environment; (3) depth of water table, where susceptibility decreases with increasing depth of water table; (4) depth, age and thickness of strata, where liquefaction tends to occur at a depth upwards of 20 m in younger geological units; (5) earthquake magnitude, where liquefaction is induced by magnitudes greater than M_w6.0 (Obermeier, 1996).

The 1988 M_w5.9 Saguenay earthquake was the first earthquake in eastern North America for which we have both digitally-recorded ground motion data and liquefaction observations (Tuttle *et al.* 1990). (Note: earlier events such as the Charlevoix earthquakes caused liquefaction but occurred in the pre-instrumental era.) Although Saquenay, Québec, and Ottawa, Ontario, are relatively distant from one another, both sites share similar Quaternary geological history and are overlain by units of glacial sediments (Tuttle *et al.* 1990; Lefebvre *et al.* 1992; Aylsworth *et al.* 2000). Numerous paleo-landslides in the Ottawa Valley are suggested to have been triggered by large earthquakes (Aylsworth *et al.* 2000). Although no liquefaction studies have been performed in the Ottawa area, Aylsworth *et al.* (2000) reports severely distorted sediments, suggesting that liquefaction is possible in the Ottawa area.

HAZUS methodologies state that the relationship of the probability of liquefaction for a given susceptibility qualifier is defined in Equation 1, where $P[Liquefaction_{SC} \mid PGA = a]$ is the conditional liquefaction probability for a given susceptibility qualifier at a specified peak ground acceleration (PGA). The liquefaction susceptibility qualifiers of geological units within the study area were determined based on the methodology of Youd and Perkins (1978).

$$P[Liquefaction_{SC}] = \frac{P[Liquefaction_{SC} \mid PGA = a]}{K_M K_W} \cdot P_{ml} \qquad [1]$$

K_M is the moment magnitude (M_w) correction factor as defined in Equation 2. The moment magnitude correction factor (K_M) is used when moment magnitude is not $M_w = 7.5$. K_W is the groundwater correction factor, as defined in Equation 3. The ground water correction factor is used when water depth is not 5 feet, where d_w is the depth to the groundwater in feet.

$$K_M = 0.0027M_w^3 - 0.0267M_w^2 - 0.2055M_w + 2.9188 \qquad [2]$$

$$K_W = 0.022d_w + 0.93 \qquad [3]$$

P_{ml} is the proportion of the geological unit susceptible to liquefaction. Geological units will have natural variation (grain size, deposit thickness, etc.) throughout individual units. Therefore a probability factor that quantifies the proportion of a geological unit or P_{ml} to liquefy is applied.

Relationships between liquefaction probability and PGA for each susceptibility qualifier are defined by Liao *et al.* (1988) and are based on empirical procedures and statistical modeling of the empirical liquefaction catalogue.

To be consistent with our estimated ground motions, liquefaction probability was assessed using the PGA associated with 2% in 50 year probability and the associated magnitude was arbitrarily assigned to be 6.5 (see Adams and Atkinson, 2003); this can be refined in future studies. The model revealed that based on the probability of liquefaction, the susceptibility class was 0, with an exception of the uncompacted fill which was classified as 2, as shown in Figure 4. Liquefaction susceptibility classes were assigned ranging from 0 to 5, with 0 being no chance of liquefaction. These results are reasonable – based on the dense soils classified as NEHRP B or C we would not expect liquefaction, so the probability for B and C class sites should be calculated as very small. On the other hand, liquefaction on pockets of uncompacted fill is quite likely.

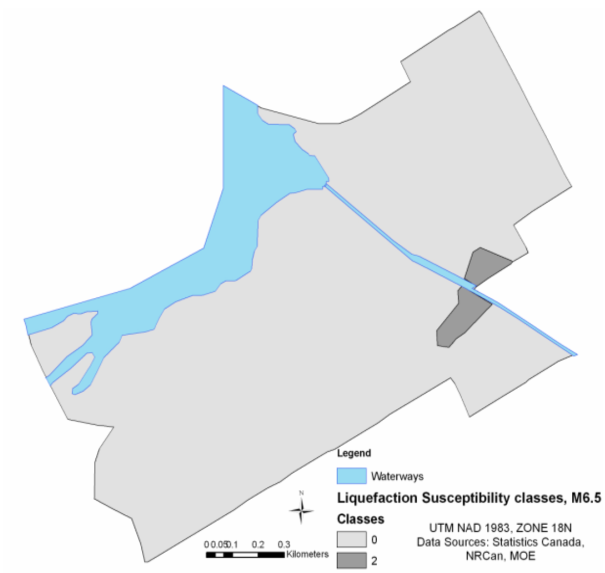

Figure 4. Probability of liquefaction map for M_w6.5 scenario. (Data sources: NRCan, MOE, Stats Canada)

2.3.4 Landslide Susceptibility

The area adjacent to the Ottawa River is located atop of a Paleozoic bedrock unit which stands up to 35 m above the water surface and considered an area vulnerable to a landslide. In ArcGIS, layers of elevation, water depth and surficial geology data were used to provide the necessary information to classify landslide susceptibility based on HAZUS methodology.

First, the elevation data was used to determine the angle in degrees of the slope. Second, the rock unit was classified into a geologic group, where certain geologic groups are more susceptible to landslides. For example, strongly cemented rocks are less susceptible to failure than argillaceous rocks. Last, the water depth layer was used to determine whether the groundwater level was found within or below the level of sliding along the steep banks of the Ottawa River.

An upper and lower bound of landslide susceptibility exists and is based on seasonal variations in groundwater level. The ground motions presented in Adams and Halchuk (2003) were compared with the critical accelerations presented in the HAZUS methodologies and results showed that only a small region of the study area is at risk of a landslide. This region extends from behind the Supreme Court of Canada and stretches eastward to the Alexandra Bridge. Landslide susceptibility classes were assigned ranging from 0 to 10, with 0 being no chance of landslide. (Note: the HAZUS methodology to determine landslide susceptibility is very simple and does not consider the dip of the layers and the degree of fracturing).

3. DATA PREPARATION

All inventoried data were converted into a digital format. A GPS was used in the field to locate structures; however, high-rise buildings in the commercial district of downtown Ottawa interfered with satellite reception of the system. Therefore, field data and georeferenced digital aerial photographs were used to determine geographic coordinates.

Once building and structure coordinates were determined, point files were created in ArcGIS. It is essential that all data intended for GIS-based loss estimation software programs are standardized, georeferenced and transformed to the coordinate system used in the loss estimation software programs. The geographic coordinate system compatible with HAZUS was the North American Datum 1983 (NAD 83).

Framework geodatabases and boundary files were manipulated to be compatible with GIS-based loss estimation software programs. For example when creating fields within a geodatabase intended for HAZUS, common attribute information including field names and field types (small integer, long integer, float, text, etc.) must be identical or errors may arise when running the program.

Shapefiles and features classes were built with matching attributes and loaded individually into each framework geodatabase. This ensured a copy of each file was maintained and could easily be updated and reloaded.

HAZUS is specifically intended to be applied to United States scenarios. New York, a state which closely matches ground motion and geographic conditions to Ottawa, was chosen and all data was copied from the HAZUS DVDs onto a hard drive. Individual geodatabases were opened in ArcGIS and modified, in preparation for a Canadian input. The results were empty, framework databases. Intended boundary files must be translated and transformed to meet HAZUS specifications, which are based on census data and HAZUS codes. Specific “American-based” codes were applied in our Canadian simulation, for example 36089 is the code to identify the State and a specific County of New York. In essence, we “tricked” the program to accept Canadian input by erasing the data for New York and replacing it with the data for Ottawa (R. Hansen and D. Bausch, personal communication, 2007).

Once all correct reference codes were utilized, framework databases were loaded with the Ottawa data, and input into the HAZUS software program. Lastly, the configuration file was modified to enable the software program to read from the new data folder.

The approach used in this paper can be applied to larger areas such as countries on an international scale and is not specific to Canadian urban centres adjacent to the United States border. However, appropriate states should be chosen to best reflect the study area, for example Puerto Rico was used in a HAZUS study for Malta (see Hansen and Bausch, 2007).

4. DATA UTILIZATION AND SUMMARY

The resolution, quality and extent of loss estimations are directly related to the data collected, prepared and input into the software program. In this study, the data was classified as high resolution down to the dissemination area, which are subdivisions of census tracts. The high quality of data resulted from the detailed building and structure inventory on a building-by-building basis rather than from a representative area. The extent of loss estimations is related to the amount of useable geodatabases input into the program. For example, this paper did not include several utilities including potable water and waste water facilities or pipelines. It should also be noted that we did not examine the broad question of whether the damage matrices in HAZUS are suitable for typical building construction in Ottawa. This is an important topic but beyond the scope of this preliminary investigation.

A preliminary simulation using the data collected in this paper was conducted for the M_w6.5 scenario event, at 20 km, and is summarized in Table 4. Note that this is a moderately-large scenario, and not necessarily the most damaging one that could occur. Nevertheless, the projected damage is significant. Analysis of the results is beyond the scope of this paper; however, losses were concentrated in the commercial areas where the largest population is located at 2:00pm. It is expected that unreinforced masonry building types would sustain the greatest amount of damage (Bruneau and Lamontagne, 1994).

Table 4. Preliminary loss estimations of downtown Ottawa, Canada.

Losses	Estimations
Moment magnitude	6.5
R_{hypo}[1]	≈20
Physical Losses	
No. of damaged buildings	312
Complete/collapse	8
Cost[2]	$233
Social Losses	
Most damaging time	2 pm
Casualties	354
Fatalities	15

[1] Hypocentral distance measured in km.
[2] Cost in millions of dollars does not include content loss.

GIS-based loss estimation software programs, similar to HAZUS, are user-friendly and geared to those in decision-making positions in disaster management. Running simulations can identify regions of increased vulnerability which can be taken into account in mitigation strategies. Additionally, modified loss estimation programs like HAZ-Taiwan have the capability to use near real-time data to generate loss estimations immediately after an earthquake and these estimations can be used as a decision making support tool during an earthquake emergency.

Loss estimation programs bridge the knowledge of experts into a powerful support tool geared toward non-experts in disaster management at any level of government. The ability to generate preliminary damage projections of an urban centre provides an opportunity to identify vulnerable regions and prepare mitigation plan proposals which will ultimately reduce physical, social and economical losses during an earthquake.

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