Microzonation Maps for Montreal and Suburbs

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OUTLINE

- Earthquake history in the Greater Montreal
- Site amplification due to surface geology
- Site characterization
- Site-specific analysis
- Risk analysis
Earthquakes in Canada, 1627 - 2009
### RECENT EARTHQUAKES in GM

<table>
<thead>
<tr>
<th>Event</th>
<th>Magnitude</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Epicentral distance (km)</th>
<th>Number of reports</th>
<th>MMI=I-II</th>
<th>MMI=III</th>
<th>MMI=IV</th>
<th>MMI=V</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002/02/02</td>
<td>Mn3.8</td>
<td>46.06</td>
<td>-73.46</td>
<td>40-80</td>
<td>8</td>
<td>25%</td>
<td>75%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002/04/20</td>
<td>Mn5.5</td>
<td>44.53</td>
<td>-73.73</td>
<td>100-130</td>
<td>319</td>
<td>9%</td>
<td>87%</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>2010/06/23</td>
<td>Mw5.0</td>
<td>45.90</td>
<td>-75.50</td>
<td>130-160</td>
<td>267</td>
<td>42%</td>
<td>40%</td>
<td>13%</td>
<td>2%</td>
</tr>
<tr>
<td>2012/10/10</td>
<td>Mn4.5</td>
<td>45.69</td>
<td>-73.20</td>
<td>22-68</td>
<td>3445</td>
<td>20%</td>
<td>45%</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td>2012/11/06</td>
<td>Mn4.2</td>
<td>45.62</td>
<td>-75.03</td>
<td>85-120</td>
<td>326</td>
<td>39%</td>
<td>29%</td>
<td>30%</td>
<td>2%</td>
</tr>
</tbody>
</table>

DYFI map of the October 2012 event
(Source: Earthquake Canada)
SITE EFFECTS

Surface rupture

Slope failure

Amplification due to topography

Rock falls

Soil amplification

Liquefaction

McGill
SITE AMPLIFICATION due to soft soils

Accelerograms of the Val des Bois Eq.
(Source: Earthquake Canada)
SITE AMPLIFICATION due to soft soils

Thickness of soft soil and surface geology mapping
**Saguenay earthquake**

City Hall
Montréal-Est

Distance > 300 km
17 m soft clay deposit
Older building

Source: Tinawi et al. (1988) et CGC
## Site classification in the CNBC2010

<table>
<thead>
<tr>
<th>Site Class</th>
<th>Ground Profile Name</th>
<th>Average Properties in Top 30 m, as per Appendix A</th>
<th>Site Undrained Shear Strength, $s_u$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hard rock</td>
<td>$\overline{V_s} &gt; 1500$</td>
<td>n/a</td>
</tr>
<tr>
<td>B</td>
<td>Rock</td>
<td>$760 &lt; \overline{V_s} \leq 1500$</td>
<td>n/a</td>
</tr>
<tr>
<td>C</td>
<td>Very dense soil and soft rock</td>
<td>$360 &lt; \overline{V_s} &lt; 760$</td>
<td>$\overline{N}_{60} &gt; 50$</td>
</tr>
<tr>
<td>D</td>
<td>Stiff soil</td>
<td>$180 &lt; \overline{V_s} &lt; 360$</td>
<td>$15 \leq \overline{N}_{60} \leq 50$</td>
</tr>
<tr>
<td>E</td>
<td>Soft soil</td>
<td>$\overline{V_s} &lt; 180$</td>
<td>$\overline{N}_{60} &lt; 15$</td>
</tr>
<tr>
<td>F</td>
<td>Other soils$^{(1)}$</td>
<td>Site-specific evaluation required</td>
<td></td>
</tr>
</tbody>
</table>

Notes to Table 4.1.8.4.A.:

(1) Other soils include:
(a) liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils, and other soils susceptible to failure or collapse under seismic loading,
(b) peat and/or highly organic clays greater than 3 m in thickness,
(c) highly plastic clays ($PI > 75$) more than 8 m thick, and
(d) soft to medium stiff clays more than 30 m thick.
Site characterization

Shear wave velocity measurement guidelines for Canadian seismic site characterization in soil and rock, J.A. Hunter and H.L. Crow (Editors), Geological Survey of Canada, OFR-7078.

Borehole survey:
Sismique réfraction et réfraction

Vs₃₀₀ = 362 m/s
Seismic reflection and refraction

<table>
<thead>
<tr>
<th>Velocity (m/s)</th>
<th>Intercept Time (ms)</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>0</td>
<td>0.65</td>
</tr>
<tr>
<td>152</td>
<td>20</td>
<td>5.63</td>
</tr>
<tr>
<td>204 (251)</td>
<td>80</td>
<td>23.9</td>
</tr>
<tr>
<td>3750 (2709)</td>
<td>285</td>
<td></td>
</tr>
</tbody>
</table>

Total depth to bedrock = 30.2 m
LAND STREAMER
Sesmic reflection and refraction
Ambient Noise (H/V)

H/V forward modeling
Sites investigated using invasive and non-invasive seismic measurements methods
SITE CLASSIFICATION OF SURFACE GEOLOGY

Fundamental period of resonance $T_0$ using H/V method
3D Surface Geology Model
Depth-velocity curves

Vs for clay materials (m/s)

\[ Y = 121.2 + 40.8 \times X^{0.43} \]
\[ R^2 = 0.43 \]

\( Z (m) \)

Vs for sand materials (m/s)

\[ Y = 144.8 + 36.8 \times X^{0.57} \]
\[ R^2 = 0.49 \]

- Land streamer sites
- MASW sites
- 95% Pred Lim
Soil classes based on $T_0$ using H/V method

**Vs30 SOIL CLASSIFICATION**

Model based on a relation $Vs30-F_0$

- **Class D** ($180 < Vs30 < 360$ m/s)
- **Class C** ($360 < Vs30 < 760$ m/s)
- **Class B** ($760 < Vs30 < 1500$ m/s)
- **Class A** ($1500$ m/s $< Vs30$)

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Sources:
- Rosset et al. (2012)
- Chouinard and Rosset (2011)
- Rosset and Chouinard (2009)
Damage estimate can be performed using a specific seismic scenario
GM is in a moderate seismic zone where the occurrence of a large earthquake can have significant impact.

Site classification mapping following the NBCC2010 is available but needs to be completed improved and expanded.

Map shows zones with expected site amplification:
- Evaluation of vulnerability of existing buildings
- Evaluate risks for various seismic scenarios
- Develop more accurate Shake Maps