SEISMIC RISK MITIGATION FOR THE MONTREAL URBAN COMMUNITY. EVALUATION OF SOIL AMPLIFICATION ; DEVELOPMENT AND APPLICATIONS

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ABSTRACT

Recent destructive earthquakes have clearly shown that near-surface geological and topographical conditions play a major role in the level of ground shaking. In post-disaster reconstruction as in mitigation, information on soft soil response to moderate earthquakes becomes of prime importance. In the framework of a seismic risk study of Montreal (Canada), a methodology for seismic zoning in urban areas is validated. It is based on field investigations coupled with numerical modelling. The field approach is emphasized as a fast and inexpensive method well-adapted for urban environments using ground ambient noise (H/V method) as the numerical one follows a 1D equivalent linear model using the code SHAKE91. Analysis on typical parts of Montreal validate the methodology and quantify the influence of quaternary deposits on the seismic response that should be included in seismic zoning.

It is now commonly accepted in the earthquake engineering community that soft soils can play a large role in ground motion and must be included in seismic zoning. Well-known examples from San Francisco and Mexico City have been extensively cited to illustrate the role of surface geology on seismic waves. In both cases, soft soils have increased the ground shaking and played a major role in human and economic losses. The recent destructive earthquakes of Northridge (1994), Kobe (1995), Armenia (1999), Colombia (1999) and Turkey (1999) have shown that damage is often larger over unconsolidated deposits than on firm rock outcrops. Since river valleys are often the site of recent alluvial and glacial deposits and also prime locations for the development of urban areas, local amplification is a major concern in earthquake-prone regions (e.g. San Francisco, Lima, Bogotá, Kobé) but also in regions of moderate seismicity. In the case of Montreal, damages are noted in the masonry cladding of the City Hall of Montreal-East during the magnitude 6 Saguenay earthquake (1988). Back-analysis determined that the damage was due both the deteriorated state of the building and local amplification from the thick clayey layer at the site (Mitchell et al. 1990). Similar examples could be mentioned in Europe and particularly in regions with low rate seismic activity as attested by recent intermediate magnitude earthquakes in Liege (Belgium, 1983), Roermont (The Netherland, 1992) and Meythet (France, 1996). In the framework of a seismic risk analysis of the Montreal Urban Community (MUC), a methodology is developed and applied at different pilot zones to investigate the effect of soft soil on seismic response (Rosset et al., 2003).

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Since decades, development of numerical and instrumental techniques to estimate site effect have improved the understanding of the phenomena. Basically, more complex is the technique (i.e. its capabilities to consider multi-dimensional effects), more limited is its application at large scale because of the lack of available sub-surface data. Amongst existing instrumental and numerical techniques (e.g. Riepl-Thomas and Cotton (1999) for detailed review), ambient noise recording and 1D modelling are used in a complementary manner. The instrumental technique, based on the H/V method (Nakamura, 1989), is a fast and low cost means of investigation in urban areas. It uses the spectral ratio between horizontal and vertical ambient noise records to estimate the fundamental frequency of a site (Bard, 1999). The 1D modelling using SHAKE91 (Idriss and Sun, 1992) is a simple but robust assumption to analyse the equivalent linear seismic response of a site. Such a methodology is able to give spectral and temporal features of the dynamic soft soil response in urban areas. It remains the first step to building and lifelines risk mitigation in case of major earthquake.

The moderate seismic activity of the Western Quebec Seismic Zone (WSQZ) is attested by historical as well as recent earthquakes which are controlled by two bands (Adams and Basham, 1991). The first band follows the Ottawa and St. Lawrence rivers and is the site of historical magnitude 6 earthquakes near Montreal in 1732. This earthquake and others are correlate with a zone of normal faulting of Cambrian-Paleozoic age, which may represent a failed rift. The second band is oriented NW-SE and extends from Montreal to the Baskatong Reservoir (200 km north to Ottawa). Although the relation between epicentres and local tectonics is not clear, crust doming and fracturing over a hot spot is one of the most realistic explanations. The most recent seismic hazard studies indicate that the expected peak ground acceleration for Montreal is 0.16g for a return period of 475 years (Adams et al., 1999). Deaggregation of the seismic hazard curve points out that the corresponding most likely event has a magnitude of 6.5 at an epicentral distance within 50 km of Montreal (Adams and Atkinson, 2002).

The quaternary history of the island of Montreal is marked by repeated glaciations depositing, during the Wisconsinan (125000-10000 BP), three episodes of till. The land was depressed after the ice retreated, and was covered by silt- and clay-sized deposits (Leda clay) from the Champlain Sea and by coarser sediments from the St. Lawrence river before the land emerged; these comprise the superficial deposits important for the microzonation.

Seven zones with soil profiles that are typically associated with large amplifications have been selected and surveyed. These correspond to typical sequences of deposition during the quaternary but also to representative built environments of the MUC as shown in Figure 1. Over 350 sites were investigated with the H/V method and data from over 500 boreholes was compiled to compute the seismic response of investigated sites using a set of real and synthetic earthquake records and specific properties of soils (Rosset et al., 2003). Scenario are proposed for 4 bands of excitation's period in order to deal with the lack of real strong motions in the WSQZ.

Comparative analysis of instrumental and numerical results show the good agreement between obtained frequencies of resonance in respect to available information for the numerical analysis (Figure 2). A relationship is established between the thickness of clay deposits and the fundamental mode of resonance in zone MONT2 that could be extrapolate in other clay areas (Figure 3). At the end, each zones is mapped in terms of predominant period of resonance and amplification factor. For the latter parameter, 4 maps are proposed that figure out pessimistic and optimistic scenarios in term of ground shaking. An example is illustrated in Figures 4 and 5 for zone MONT2.

The complementary use of instrumental and numerical approaches reveals to be a good compromise in the MUC as available data are relatively sparse into a large area. The uncertainty in the input parameters of the numerical calculation is marked as an important improvement for further investigations, in particular for shear velocity. In this way, specific software analysis tools have been developed to implement the methodology and to update maps as new data becomes available (Rosset, 2002 ; De la Puente and Rosset, 2002).

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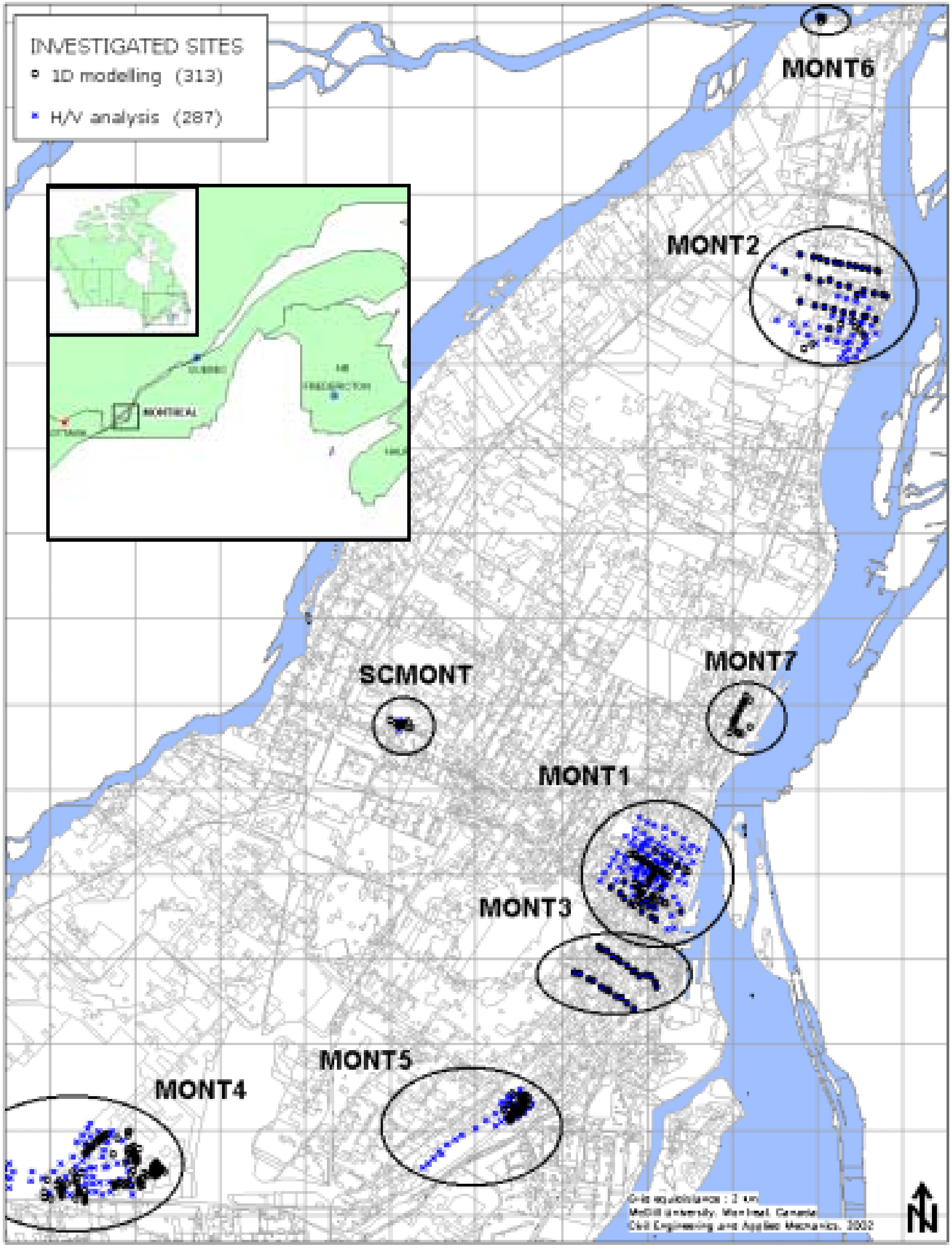
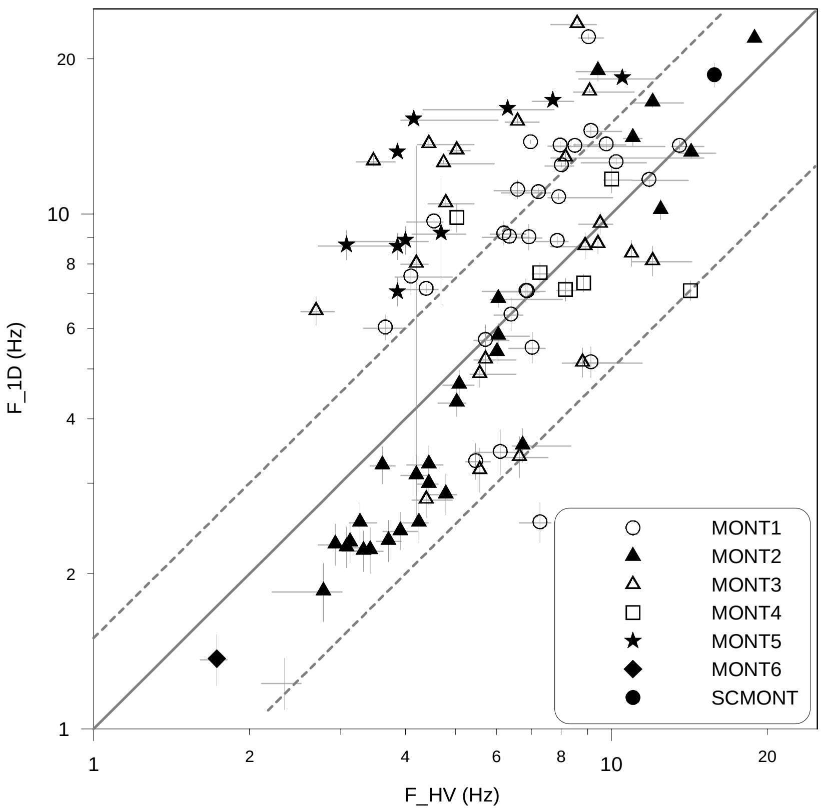


Zone ID	Soft soils	Thickness (m)	Built environments
MONT1	clay - sand	0-27	Residential and historical buildings
MONT2	clay	0-18	Industrial and residential buildings
MONT3	clay - sand - till	0-24	High-rise buildings
MONT4	clay - sand	0-20	Industrial facilities and airport
MONT5	mud - clay	0-30	Major highway and railroad networks
MONT6	clay	20-25	Major highway and railroad bridges
MONT7	clay - peat	1-30	Port of Montreal *(no H/V analysis)*
SCMONT	till	3-5	Emergency Preparedness Center

Figure 1 : Selected zones into the Montreal Urban Community and analysed sites with numerical (1D modelling) and instrumental (H/V method) approaches.



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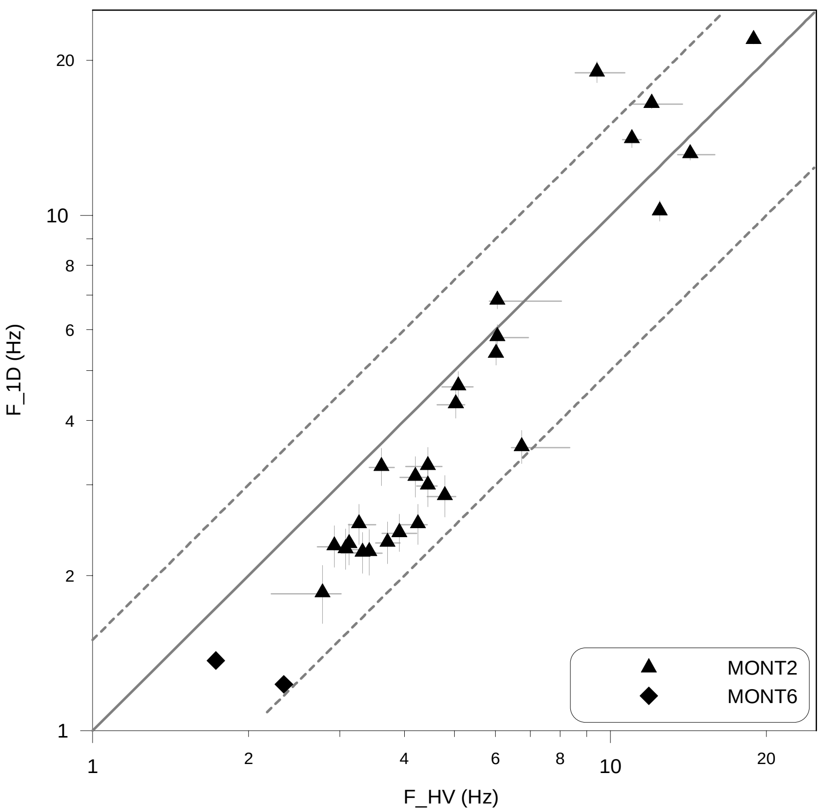
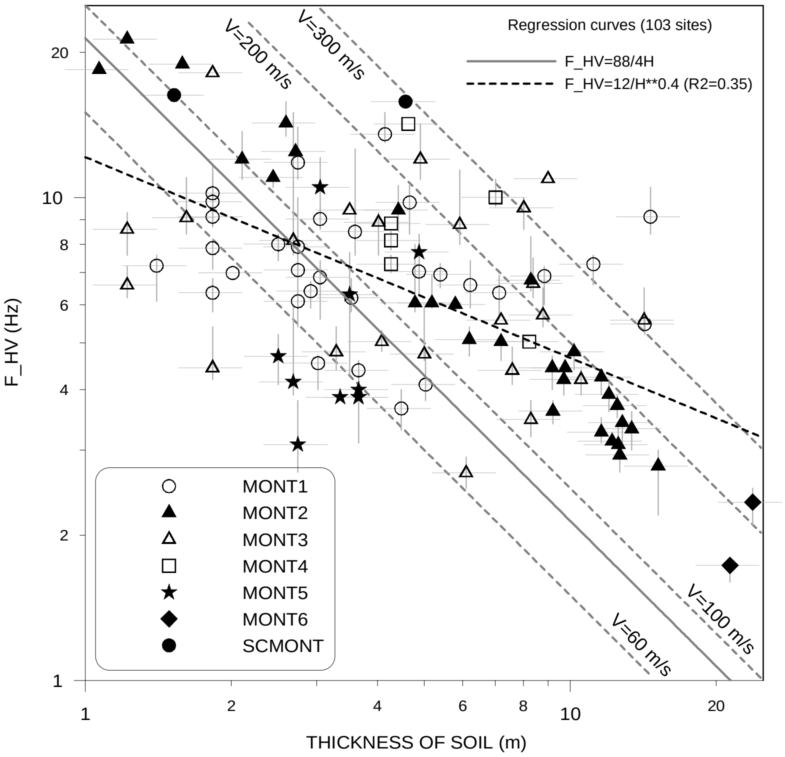
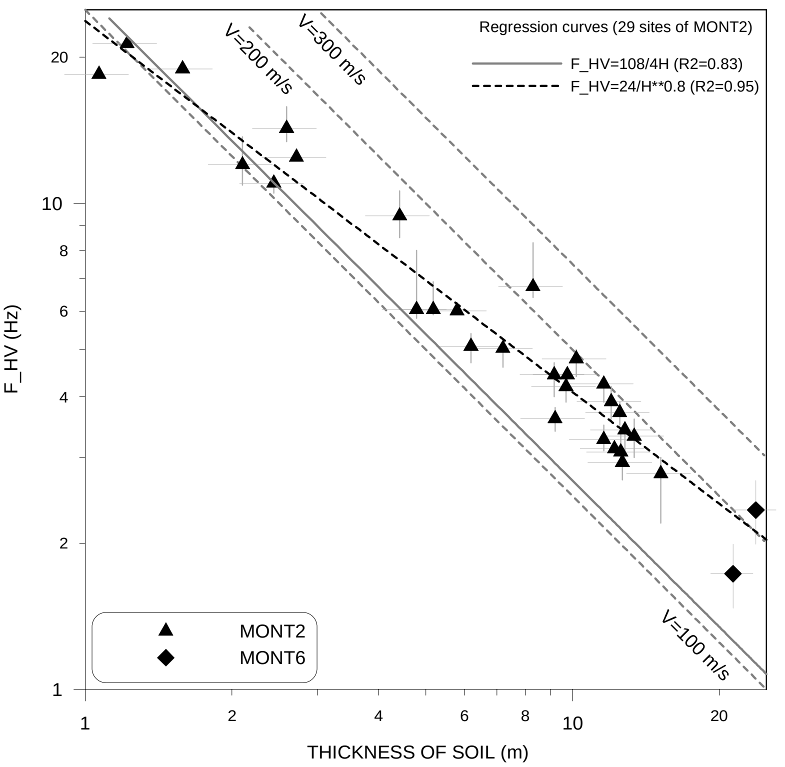


(b)

Figure 2 : Correlation between predominant frequencies of resonance obtained with instrumental (F_HV) and numerical (F_1D) approaches for each zones. Black line represent the linear relationship through origin as dashed lines are the 50 % confidence intervals. Lower and upper bonds for F_HV and F_1D are given (a) for the sites of all zones (b) for sites of zones MONT2 and MONT6.

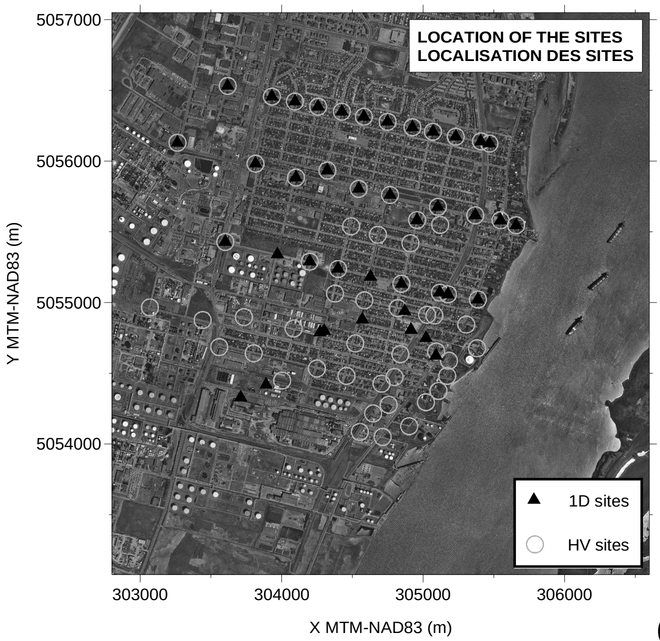


(a)



(b)

Figure 3 : Predominant frequency of resonance derived from the H/V polarization peak (F_HV) versus the thickness of soft soils overlying tills for each zones (logarithmic scales). Grey dash lines represent a constant velocity V. The grey line is the best estimate of V from the samples and black dash line is the power law fitting the samples (equation and R-square are given top-right). Lower and upper bonds for F_HV and a 10% confidence interval for the thickness are given (a) for the whole dataset (b) for sites of zones MONT2 and MONT6. in this case, regression curves are calculated with sites of MONT2 exclusively.



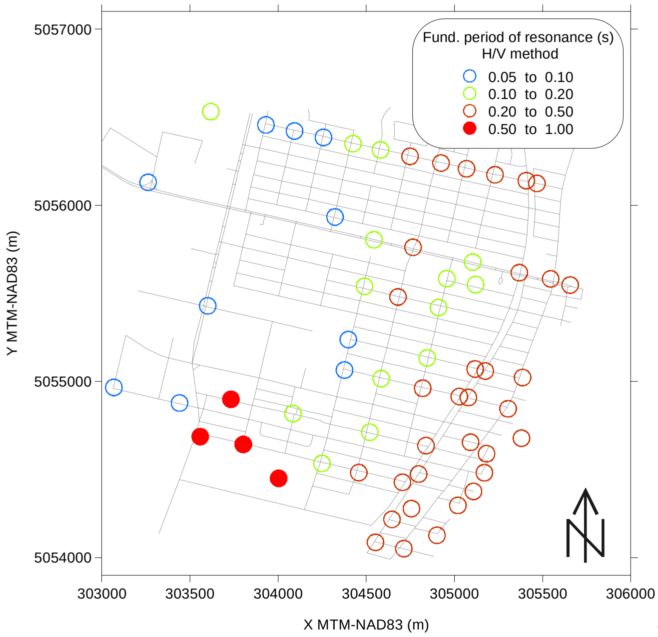
(a)

Figure 4 : Seismic soil response in terms of fundamental mode of resonance in the case of zone MONT2

(a) Investigated sites with both instrumental and numerical approaches located on the aerial photography (Courtesy of the Geographical Dpt of the McGill University)

(b) Fundamental period of resonance derived from ground ambient noise analysis.

(c) Fundamental period of resonance derived from 1D modelling. The average value over the set of 17 runs is represented and an interpolated grid is calculated by kriging method.



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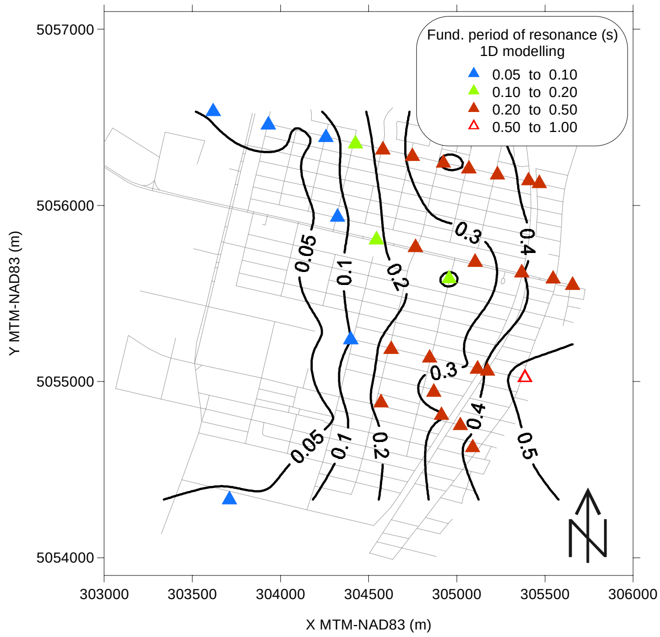

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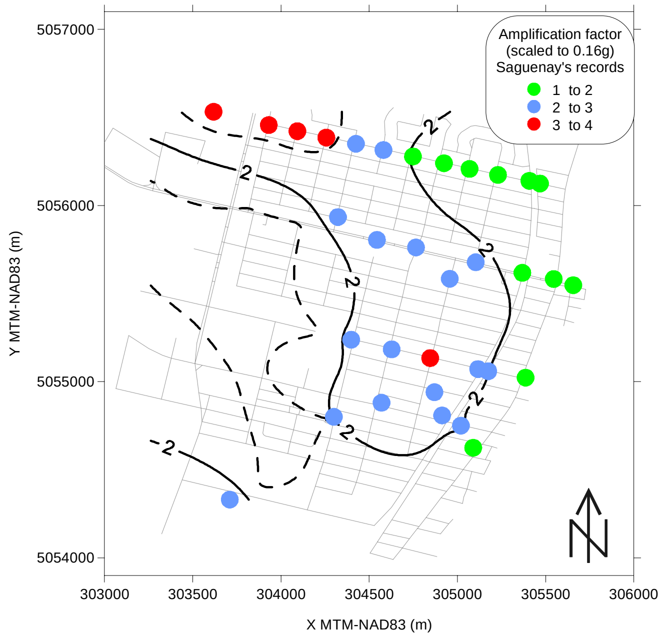


(a)

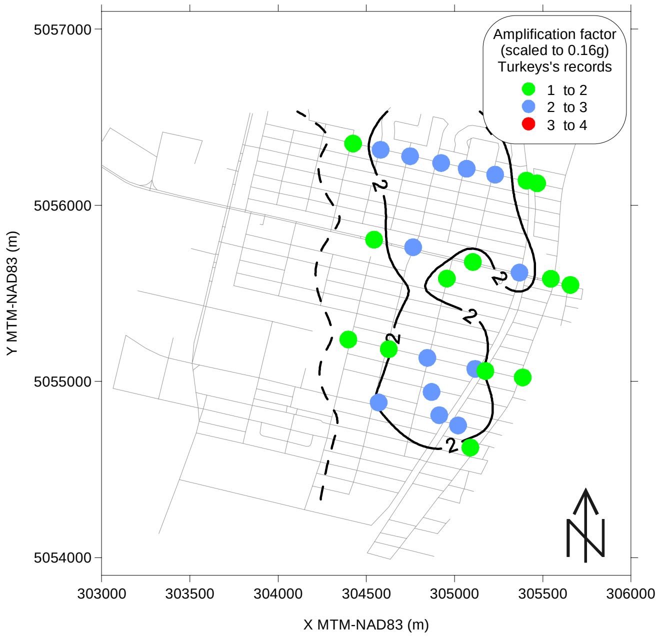
Figure 5 : Seismic soil amplification in the case of zone MONT2

(a) Low period scenario. 5 records of the Saguenay earthquake, 1988 are used for calculations.

(b) Intermediate period scenario. A recording of the Izmit and Duzce earthquakes, 1999 are used for calculations.

(c) High period scenario. A recording of the Imperial Valley, 1940 and Loma Prieta, 1989 earthquakes are used for calculations.

PGA values of the input records is scaled to 0.16g in accordance to the nominal acceleration given by the National Building Code of Canada, 1985.



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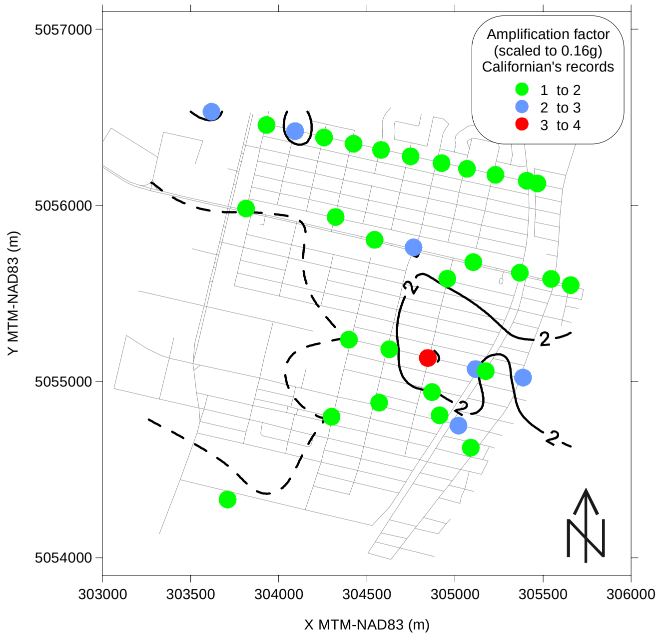

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