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Monofrequency *in situ* damping measurements in Ottawa area soft soils

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ABSTRACT

In Ottawa, Canada, unusually high amplification ratios have recently been measured in clayey silts (called 'Leda Clays') at low levels of earthquake-induced ground shaking. However, the contribution of seismic Q, or material damping ($\xi=1/2Q$), to the overall ground motion at soft soil sites across the city is not well understood. This research investigates attenuation measurements in soft soils ($V_s<250$ m/s) for ongoing seismic hazard evaluation in the Ottawa area. The work focuses on *in situ* measurements of damping in two deep boreholes drilled into Leda Clay. To investigate the possibility of frequency-dependent dynamic properties of these materials at low strains, a new approach to the spectral ratio technique has been developed for the measurement of Q_s in the field using a mono-frequency vibratory source (generating signals between 10 and 100 Hz), and two identical downhole 3-component geophones. Monofrequency signals also allowed for the measurement of dispersion (variation of velocity with frequency). Analysis of the data show that dynamic properties are, for the most part, independent of frequency in the homogenous silty soils, yielding negligible variation in shear wave velocity (<2 m/s) across the frequency test band, and small strain Q_s's ranging from 170 to 200 (damping of 0.25–0.30%) over soil thickness intervals ranging from 10 to 60 m. At intervals within 20 m of the ground surface, laminated silt and clay beds of elevated porosity are found to have slight influence on the frequency dependence of damping for frequencies greater than 70 Hz (damping increase to 0.6%).

1. Introduction

Seismic data collected in the National Capital Region of Canada during weak motion (M2.0–M3.0) earthquakes at seismograph stations founded on rock and nearby soil sites have produced horizontal/vertical (H/V) component spectral ratios of 80^+ at site resonant frequencies. Fig. 1 presents computed horizontal velocity spectra of rock and soil stations located 1.6 km apart, showing the broadband and resonant amplification at the soil site, resulting from a M3.0 earthquake with an epicentral distance of 77 km. Local citizens living over soft soil deposits in the city suburbs have described noticeable shaking during low magnitude earthquakes, equivalent to Mercalli intensity II and III, up to IV in rare cases. However, the level at which damping at low strains contributes to the attenuation of seismic waves is not well understood in regional soft soils.

The effects of intrinsic shear wave attenuation (also named seismic Q_s, or material damping, ξ, where $Q=1/2\xi$) in rock have been of interest for many decades and the subject of study both in laboratory and *in situ*. While the effect of Q_s in near surface soft soils ($V_s<250$ m/s) has received less attention, it has important implications in the field of seismic hazard studies. Structures founded on soils with periods close to that of the thickness of the deposit may undergo more intense shaking due to a resonance effect set up between structure and soil. This building–soil interaction is important because the amplification factors provided in the 2005 National Building Code of Canada (2005 NBCC) may not be sufficiently high at the resonance period of a site [1], acknowledging the potential for deamplification within the non-linear range. Hence, attenuation in soils is a particularly important property to understand, since the resonance effect in soft soils will be longer lasting if soil dissipation of waves trapped in the near surface is low.

In near surface soils, however, there is no consensus in the literature on how best to measure Q_s *in situ*, and the reported ranges of Q_s vary widely, even within the same material types. In papers published on low-strain *in situ* Q_s measurements in soft soils found within seismically active regions of North America, values varied from 10 to 200 (damping = 0.25–5.0%) (see Table 1).

To measure damping in this study, a variation of the frequency–domain spectral ratio technique was adopted using a vibratory source to generate mono-frequency signals over a frequency band between 10 and 100 Hz. Amplitude attenuation and dispersion measurements were performed in a 96-m deep Geological Survey of Canada (GSC) borehole drilled in 2008 within

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