Preliminary results of the seismic microzonation and site characterization of three major cities of Gangwon province, Korea using Rayleigh-wave Dispersion curves

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Summary

To define the seismic site conditions in the three major cities (Chuncheon, Wonju and Gangneung) of Gangwon province, Rayleigh-wave data were recorded using both passive and active sources. An 8-kg wooden hammer was used as an active source. The seismic waves were recorded for 8 to 64 s using twelve or twenty four 4.5-Hz geophones and digitally recorded on a 24-channel engineering seismograph at 125 to 500 Hz sample rates. Phase-velocity spectra of the Rayleigh waves were obtained by the extended spatial autocorrelation method. Shear-wave velocity models were derived from the estimated dispersion curves determined from the phase velocity spectra using the damped least-squares inversion technique. From these 1-D velocity models, estimated values of Vs_{30} in Chuncheon, Wonju and Gangneung are 402±13 m/s, 418±13 m/s, and 365±15 m/s, respectively. Most of the investigated areas in those cities belong to NEHRP site class D, C, E and B. In downtown and agricultural areas, both the lower estimates of Vs_{30} and thicker overburden layer make them more prone to significant ground amplifications. The Vs_{30} estimates show that Chuncheon and Wonju are at lower risk of ground shaking effects than Gangneung in case seismic activities.

Introduction

Soft and unconsolidated sediments overlying hard bedrocks substantially influence the ground motions during the propagation of seismic waves through the geologic layers, even in the case of moderate seismic activity. Large devastating earthquakes have often affected urban population and infrastructures. Spatial distribution of the soft soil layer is of vital importance for the assessment of seismic characteristics in urban sites and preventive plans to reduce economic loss and human casualty. Large spread of population into the low altitude areas that are attractive for the construction of hospitals, schools, and industries are seismically unfavorable as such sites are more likely exposed to intensive ground shaking effects.

Korean peninsula (KP) in the proximity of 'Ring of Fire' is tectonically controlled by the relative movement of Pacific, Philippine, and Eurasian plates. It is a stable landmass, which is seismically located in the low to moderate seismicity region. However, numerous earthquake records could be found from the ancient history (Chiu et al., 2004). Most of the earthquake events in the KP is dominantly due to the strike-slip faulting and reverse- or dip-slip components (Fattah et al., 2014). Uljin earthquake of M_W 5.1 occurred in May, 2004 at 200 km south of Wonju and 160 km south of Gangneung (Kang et al., 2004). A moderate-sized earthquake (M_L = 4.5) known as Odaesan earthquake occurred in Gangwon province in January 2007 (Jung et al., 2013) to scare many dwellers in Wonju and Chuncheon. In the KP, earthquakes greater than magnitude 4.0 occurred three times in 2013 (KMA, 2013).

Methodology

Dispersion of surface waves contained in microtremors (complex waves) can be extracted either by the frequency-wavenumber (f-k) method or spatial autocorrelation method (SPAC). The f-k method uses a narrow band of frequencies for the required array-length and lacks accurate measurement of phase-velocity of surface waves (Okada, 2003). The basic principle of SPAC (Aki, 1957) is to estimate a relationship between temporal and spatial spectra of surface waves to derive the dispersion curves of phase velocity. The complex microtremor signals are the result of stochastically spatiotemporal stationary process.

Passive (microtremors) and active seismic data were used in this study since no significant amount of strong motion data were available to delineate site classes based on theoretical or empirical approach.

Data Acquisition and Processing

Active and passive surface waves were recorded using a 24-channel engineering seismograph (Geometrics, Geode) during the period of January, 2012 to November, 2014. Twelve or twenty-four 4.5-Hz geophones were laid out in linear or L-shape arrays with receiver intervals of 3 to 5 m. The geophones were spaced at optimum intervals to record good resolution data at required penetration depths. An 8-kg wooden hammer was used as an active seismic energy source to generate surface waves. The passive and active seismic data were recorded for 8 to 64 s, respectively. The recorded data were then digitized at 125- to 500-Hz sampling rates.

S-wave velocity (Vs) models were obtained from the dispersion curves by non-linear least squares method of Levenberg-Marquardt (Marquardt, 1963). Initial Vs models for inversion were constructed using 1.1 times of phase velocity for an estimate of Vs and the one-third wavelength approximation for depth (Hayashi et al., 2006). The initial models were constrained with a depth of 40 m and 41 layers with an identical thickness of 1 m. Initial models were then iteratively modified more than 20-times to minimize the difference between observed and computed models. The root mean squared (RMS) errors were reduced to less than 5 % to obtain the best-fit final Vs models.

V_{S30} and seismic site zonation

The time-averaged shear-wave velocity to the top 30-m depth (V_{S30}) is one of the most widely used indicator to identify the site response during the low to moderate seismicity. V_{S30} is a metric to define the seismic site classes and site amplification. Due to the widespread acceptance and precision of V_{S30} in predicting ground motions, many of the building design codes including Korean building code have adopted it as a benchmark to describe the seismic site conditions. In areas of low to moderate seismicity like Korea, microtremors can be a good alternative because of the lack of strong ground motions. In the present study, the following relationship was used to compute V_{S30}:

$$Vs_{30} = \frac{\sum_{i=1}^{n} 30}{\frac{\sum_{i=1}^{n} di}{\sum_{i=1}^{n} Vsi}} \qquad (1)$$

Where di is estimated layer thickness of i-th layer and n refers number of distinct layers in the top 30 m.

The estimated V_{S30} values in Chuncheon, Wonju and Gangneung range in 226 m/s to 583 m/s (mean= 402 m/s), 239 to 747 m/s (mean=418), 144 to 938 m/s (mean= 365 m/s), respectively (Fig. 1). According to the Korean building code for seismic design, the computed V_{S30} indicate that the investigated sites in Chuncheon, Wonju and Gangneung are classified as C (88 %) and D (12 %); C (55%) and D (45 %); and D (58%), C (34%), E (4%), and B (4%), respectively (Fig. 2). At many sites in the downtown area of Gangneung (12%), S-wave velocity are lower than 200 m/s and consequently substantial risk of soil-liquefaction is apprehended in the case of strong ground motions (Asten et al., 2014).

Table 1. V_{S30} estimates and seismic microzones for 260 sites in three most densely populated cities of Gangwon province, Korea.

		Chuncheon	Wonju	Gangneung
V_{S30} (m/s)	Min	225.7	238.9	143.8
	Max	582.9	746.8	937.7
	Average	401.6	417.6	364.8
	Standard Error	12.6	13.5	14.6
	No. of Samples	46	78	136
Seismic Microzonation	NEHRP class (1994)	D and C	D and C	E, D , C and B

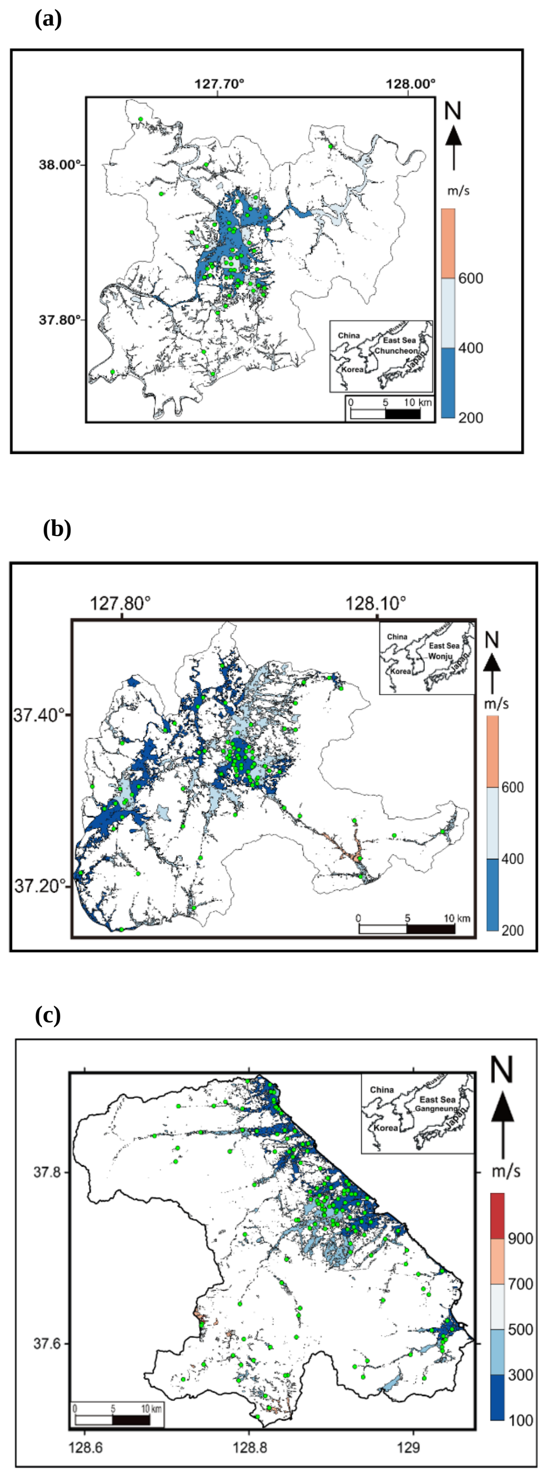

Fig. 1. Maps showing the estimated average shear-wave velocity to the top 30 m depth (V_{S30}) for 260 sites (solid green circles) in **(a)** Chuncheon, **(b)** Wonju and **(c)** Gangneung, Korea. The inset maps show locations of Chuncheon, Wonju, and Gangneung in Asia-pacific region.

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Results and Conclusions

Shear-wave velocity profiles computed by inverting dispersion curves of Rayleigh waves indicate that the estimated average Vs_{30} are 402±13 m/s, 418±13 m/s, and 365±15 for Chuncheon, Wonju and Gangneung, respectively (Table 1). The yielded maps represents that eastern side (Gangneung) of Gangwon province with the lower estimates of Vs_{30} is more prone to site amplification than western and central parts. The lower estimates of Vs_{30} are along the east coast of Korea where earth surface is mostly covered by Quaternary alluvium and fluvial terrace deposits. Most of the investigated sites in eastern areas of Gangwon province are characterized as site classes D and E, whereas Wonju and Chuncheon belong to site classes C and D of National Earthquake Hazard Program (Fig. 2). Western areas in Gangneung are mostly assigned to C and B seismic site class and less prone to significant ground shaking compared to the east. Vs_{30} estimates show that Chuncheon and Wonju are at lower risk of ground shaking effect than Gangneung in case seismic activities. Downtown and agricultural areas of Chuncheon, Wonju and Gangneung with thicker overburden layers and lower Vs_{30} are seismically more prone to ground amplification than the mountainous area.

Acknowledgements

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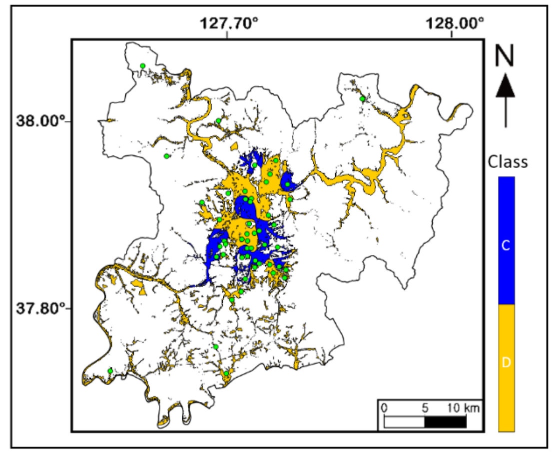
(a)



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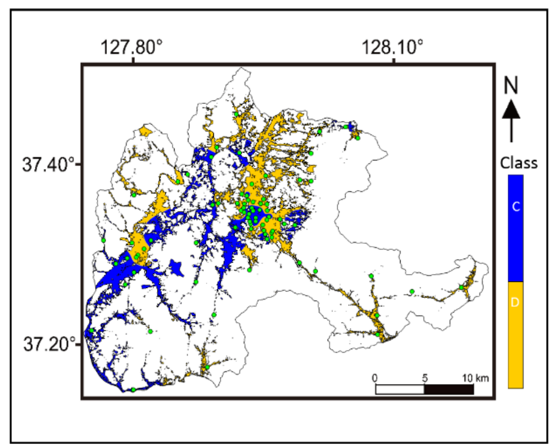

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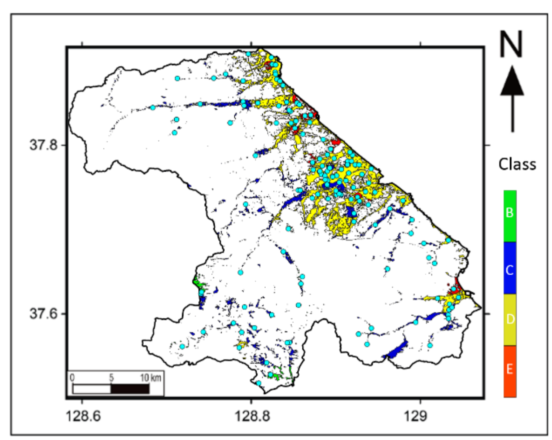

Fig. 2. Maps showing seismic site zonation for 260 (solid green and cyan circles) sites in **(a)** Chuncheon, **(b)** Wonju and **(c)** Gangneung, Korea. Letters B (760-1500 m/s), C (360-760 m/s), D (360-180 m/s), and E (<180 m/s) in the color bar on the right of each zonation map represent the site classes of the NEHRP (1994).

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