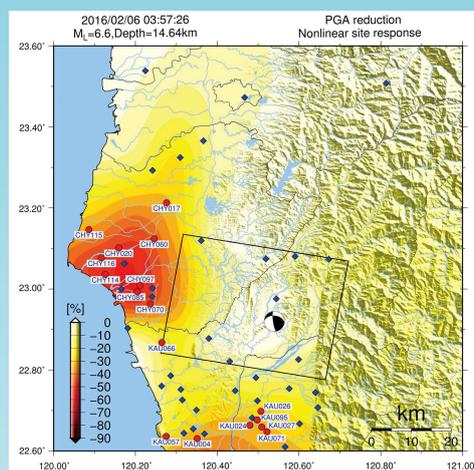


# Earth, Planets and Space

Effect of Surface Geology on Seismic Motion:  
Challenges of Applying Ground Motion Simulation  
to Seismology and Earthquake Engineering



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## PREFACE

## Open Access



# Special issue “Effect of surface geology on seismic motion: challenges of applying ground motion simulation to seismology and earthquake engineering”

Kuo-Liang Wen<sup>1</sup>, Pierre-Yves Bard<sup>2</sup>, Francisco-José Sánchez-Sesma<sup>3</sup>, Sadanori Higashi<sup>4</sup>, Tomotaka Iwata<sup>5\*</sup> and Takuto Maeda<sup>6</sup>

In the past few decades, numerous studies on the modification of seismic ground motion by surface geology and subsurface structures (Effects of Surface Geology on seismic motion, ESG) have been carried out for improving both our understanding of strong ground motion characteristics during destructive earthquakes and our ability to perform reliable ground motion predictions of future events. This has been enabled by increasing amounts of strong motion data and computing power. Research into the quantification of ESG, and accounting for those effects in everyday design and engineering practice is a key element in the mitigation of earthquake disasters, which are still occurring all over the world.

ESG International Conferences have been held in 1992 (Odawara, Japan), 1998 (Yokohama, Japan), 2006 (Grenoble, France), 2011 (Santa Barbara, USA) and 2016 (Taipei, Taiwan). This 5th International Conference on the Effects of Surface Geology on seismic motions (ESG5) was successful in several respects. It gathered an important number of researchers, field engineers and graduate students from all over the world. The ESG5 proceedings include a large amount of significant information. In order to offer the research community a collection of peer-reviewed contributions, the ESG5 Organizing Committee arranged for the publication of a special issue on recent advances into ESG research in *Earth, Planets and Space* (EPS), a journal published by Springer. This follows the last

special issue on ESG published in 1992 in the *Journal of Physics of the Earth* (a journal which was merged with EPS in 1998).

This new special issue is a compilation of 18 papers on ESG research, including topics such as seismic ground motion observation; analysis and interpretations, including nonlinear site response; utilization of microtremors; and development of simulation methodologies for strong ground motion prediction.

Seismic observation analysis has always been a key research topic of ESG. Uetake (2017) reports interesting behavior in long-period ground motion recorded in the Kanto area, Japan. He demonstrates that the observed long-period ground motions significantly differed among several distant earthquakes, although they had similar locations, sizes and mechanisms. He shows that the details of the velocity structure in the earthquake source region were the cause of the observed large waveform packet, demonstrating the importance of considering structural inhomogeneities in the source side for long-period ground motion prediction. Bijukchhen et al. (2017) use the observed strong ground motions in the Kathmandu valley during the 2015 Gorkha mainshock and aftershocks, to derive a one-dimensional velocity structure model beneath the observed stations and to compare them with the theoretical earthquake H/V ratios. A unique strong ground motion study was conducted by Sbaa et al. (2017), who performed six-degrees-of-freedom observations using translational and rotational sensors at two nearby sites in Kefalonia Island, Greece, located on rock and soft soil conditions,

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respectively. They found that the dependence on site conditions is stronger for torsional motion (rotation around the vertical axis) than for rocking motion (rotation around horizontal axis), which they interpreted as being a result of more energetic Love waves on soft site conditions compared to Rayleigh waves. Kagawa et al. (2017) compare the observed ground motion variations in the source region of the 2016 Central Tottori earthquake to the map of predominant site period derived from dense microtremor observations in the area. They show that larger peak ground accelerations correspond to shorter predominant periods, and also report significant period shifts at some intermediate period sites during the main shock, which they interpret as being related to nonlinear site response.

Effects of nonlinear site response and/or liquefaction significantly impact strong ground motion characteristics. Ren et al. (2017) quantify the amount of soil nonlinearity by using various indices based on the horizontal-to-vertical spectral ratio applied to strong ground motion records obtained during and after the 2008 Wenchuan earthquake, China (Ms8.0), and investigate their correlation with loading or site parameters. Similarly, Chen et al. (2017) analyze the amount of nonlinear site response in the (estimated) strong shaking area in relation to the loading and site parameters for the 2016 Meinong earthquake and propose a method to incorporate the resulting nonlinear frequency shifts in otherwise linear stochastic ground motion simulations. Lu et al. (2017) investigate the degree of damage to low-rise buildings as a result of soil liquefaction in the superficial layer during the 2016 Meinong earthquake, Taiwan, and emphasize some nonconservative limitations of existing methods, linked to poor accounting of the underlying site conditions. Dhakal et al. (2017) transpose these nonlinear site response estimates based on H/V ratios to the ocean bottom seismogram sites of the Sagami Bay K-NET, Japan. Their observations show that the degree of nonlinearity is generally larger at the OBS sites due to the smaller threshold motions that cause a nonlinear site response, compared with the available data at land sites.

The use of microtremors has been a permanent feature of ESG studies for many decades. Recently, building on advances in the methodology of seismic interferometry of ambient noise or microtremors, Sánchez-Sesma et al. (2011) and Kawase et al. (2011) use the diffuse field theory to propose new relationships between an underground velocity model and microtremor H/V, or earthquake H/V, respectively. Sánchez-Sesma (2017) investigate the nonuniqueness issue of 1D velocity model inversions based on the H/V spectral ratio only, by inverting jointly the H/V ratio and the dispersion curves

of fundamental modes of Rayleigh and/or Love waves. Kawase et al. (2018) use statistical analysis to compare microtremor (M) and earthquake (E) H/V spectral ratios from a large set of permanent strong ground motion stations to derive simple, frequency-dependent correction factors to estimate EHVS from easily obtainable MHVS and propose a relatively simple method for the derivation of 1D velocity profiles from corrected microtremor H/V ratios. Matsushima et al. (2017) observed a directional dependence of microtremor H/V at the Onahama station, Fukushima, Japan. The directional analysis of dense, single-point microtremor measurements allowed them to identify the presence of a shallow, wedge-like lateral heterogeneity, parallel to the direction of the axis of the larger microtremor H/V amplitude, consistent with the strong motion observations. Meanwhile, Wu et al. (2017) propose a simplified approach to invert the 1D velocity structure directly from the microtremor H/V ratio, on the basis of the locked mode (“cap-layer”) approximation allowing the use of the residue theorem.

Asano et al. (2017) obtain long-period inter-station Green’s function in the Osaka sedimentary basin, Japan, using ambient noise (microtremor) cross-correlation functions. The fairly good match with the simulated inter-station Green’s functions based on the present Osaka sedimentary basin model (Sekiguchi et al. 2016) shows the applicability of noise cross-correlation for velocity model validation. Salameh et al. (2017) propose, using a case study from Beirut (Lebanon), the combination of microtremor observations at ground surface with those within buildings, coupled with a background model based on extensive site and building response calculations, to provide urban-scale damage estimates on the basis of easily available dynamic parameters (soil and building frequencies, H/V amplitude). Kleinbrod et al. (2017) show the usefulness and repeatability of ambient vibration on rock slopes to characterize unstable areas from the directional dependence and the amplitude of the H/V spectral ratios.

Finally, in order to optimize the efficiency of ground motion prediction equations and building code provisions, site characterization issues should be addressed continuously. Derras et al. (2017) use the KiK-net data to investigate the performance of several parameters as site condition “proxies” to reduce the aleatory variability of GMPEs and recommend the use of pairs of proxies. They also identify significant site response nonlinearities and discuss the ability of various site proxies and loading to account for them. The objective of Stambouli et al. (2017) is similar, i.e., to identify optimal site condition proxies, but their approach is based exclusively on 1D, linear numerical simulations, together with the use of a special kind of neural network to derive appropriate

relationships between various site parameters and site amplification functions.

This special issue presents a representative selection of recent advancements in ESG studies, including topics such as strong motion observation, field investigation of microtremor and/or seismic ground motions, their analysis using a wide variety of processing and inversion techniques, and their interpretation and comparison with forward simulation models. These studies reflect the ongoing efforts to improve strong ground motion prediction for future earthquakes. We expect new challenges and further advances of ESG studies that contribute to the reduction in earthquake disasters all over the world.

#### Authors' contributions

All authors of this article served as guest editors for this special issue. All authors read and approved the final manuscript.

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# Using ambient vibration measurements for risk assessment at an urban scale: from numerical proof of concept to Beirut case study (Lebanon)

Christelle Salameh\*, Pierre-Yves Bard, Bertrand Guillier, Jacques Harb, Cécile Cornou, Jocelyne Gérard and Michelle Almakari

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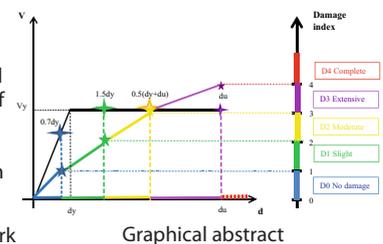
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## Abstract

Post-seismic investigations repeatedly indicate that structures having frequencies close to foundation soil frequencies exhibit significantly heavier damages (Caracas 1967; Mexico 1985; Pujili, Ecuador 1996; L'Aquila 2009). However, observations of modal frequencies of soils and buildings in a region or within a current seismic risk analysis are not fully considered together, even when past earthquakes have demonstrated that coinciding soil and building frequencies leads to greater damage. The present paper thus focuses on a comprehensive numerical analysis to investigate the effect of coincidence between site and building frequencies. A total of 887 realistic soil profiles are coupled with a set of 141 single-degree-of-freedom elastoplastic oscillators, and their combined (nonlinear) response is computed for both linear and nonlinear soil behaviors, for a large number (60) of synthetic input signals with various PGA levels and frequency contents. The associated damage is quantified on the basis of the maximum displacement as compared to both yield and ultimate post-elastic displacements, according to the RISK-UE project recommendations (Lagomarsino and Giovinazzi in *Bull Earthq Eng* 4(4):415–443, 2006), and compared with the damage obtained in the case of a similar building located on rock. The correlation between this soil/rock damage increment and a number of simplified mechanical and loading parameters is then analyzed using a neural network approach. The results emphasize the key role played by the building/soil frequency ratio even when both soil and building behave nonlinearly; other important parameters are the PGA level, the soil/rock velocity contrast and the building ductility. A numerical investigation based on simulation of ambient noise for the whole set of 887 profiles also indicates that the amplitude of  $H/V$  ratio may be considered as a satisfactory proxy for site amplification when applied to measurements at urban scale. A very easy implementation of this method, using ambient vibration measurements both at ground level and within buildings, is illustrated with an example application for the city of Beirut (Lebanon).

**Keywords:** Spectral coincidence, Nonlinearity, Seismic damage, Microtremor, Beirut, Neural network



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# Stochastic ground motion simulation of the 2016 Meinong, Taiwan earthquake

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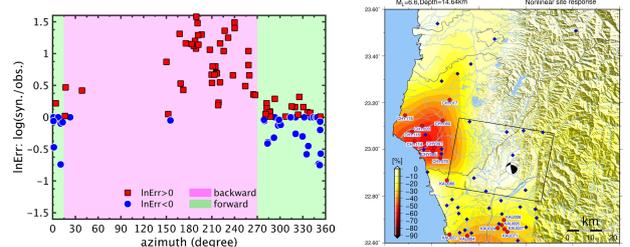
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## Abstract

We applied a stochastic method for the finite-fault modeling of strong ground motions to the 2016 Meinong, Taiwan earthquake. Newly developed attenuation models in Southern Taiwan with the frequency-dependent  $Q = 86.4f^{0.73}$  and the high-frequency decay factor  $\kappa_0$  were used in the synthetic model. The horizontal-to-vertical spectral ratios (HVSr) were calculated from weak motions and the Meinong mainshock and used for the site amplification correction of the synthetic waveforms produced by the stochastic ground motion simulation. Simulations incorporating the attenuation models and site correction improved the prediction of the S-wave envelope, duration, and peak ground acceleration (PGA). The nonlinear site response during the Meinong mainshock was identified by the degree of nonlinear site response (DNL), which is a summation of HVSr differences between weak motions and the Meinong mainshock as recorded by the Taiwan Strong Motion Instrument Program. The DNL showed a positive correlation with ground motion intensity. The surface site conditions influenced DNL strength. The percentage of PGA reduction calculated in this study can be an indicator of the spatial distribution of the degree of nonlinear soil effects on the Meinong earthquake in the time domain. Areas that had high levels of PGA reduction overlap with areas that had high liquefaction potential. Based on the residual analysis, forward directivity was identified in a  $105^\circ$  range in the northwestward direction. The amplification of forward rupture directivity was three times greater than the backward rupture directivity.

**Keywords:** Stochastic method, HVSr, Nonlinear site response, Rupture directivity



Graphical abstract

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# Directionally dependent horizontal-to-vertical spectral ratios of microtremors at Onahama, Fukushima, Japan

Shinichi Matsushima\*, Hiroyuki Kosaka and Hiroshi Kawase

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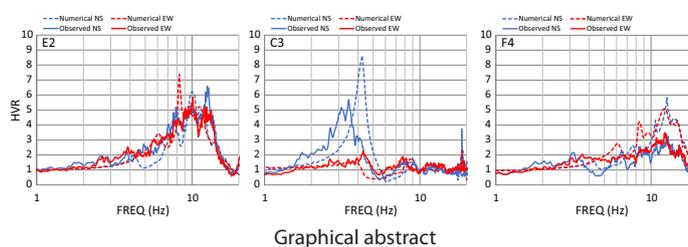
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## Abstract

As observational evidence of 3-D microtremor horizontal-to-vertical spectral ratios (MHVRs), previous studies have shown that a significant directional dependency is observed in and around Uji campus, Kyoto University, Japan. This directional dependence is considered to be the result of 2-D basin structure. In this study, we observed microtremors around a strong motion observation site of the Port and Harbor Research Institute in Onahama, Japan, and found that directional dependence of MHVRs exists in some parts of the area around the site. The directional dependence is more apparent and has a higher dominant frequency, at around 5 Hz, relative to those observed in Uji, at around 0.5 Hz. We defined a parameter  $\gamma$ , which we refer to as the “directionally dependent coefficient” to indicate the magnitude of difference between the two orthogonal components which implies the directional dependence of the MHVRs. We rotated the axes and calculated  $\gamma$  for each angle and searched for the orientation that gave the largest  $\gamma$  at a point. Points for which the axis with larger MHVR amplitude among the two axes is oriented in the NS direction are aligned in the NS direction, while points for which the axis with larger MHVR amplitude is oriented in the EW direction are aligned in the EW direction. The distribution of points with large  $\gamma$  formed a T-shaped distribution. We calculated the analytical and numerical MHVRs in order to simulate the observed MHVRs and succeeded in showing the existence of a narrow wedge. From these results, we conclude that a wedge-like lateral heterogeneity exists in the shallow subsurface of the studied area, parallel to the direction of the axis of the larger MHVR amplitude.

**Keywords:** Horizontal-to-vertical spectral ratio, Directional dependency, Microtremor, Lateral heterogeneity, Onahama



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# Estimation of 1-D velocity models beneath strong-motion observation sites in the Kathmandu Valley using strong-motion records from moderate-sized earthquakes

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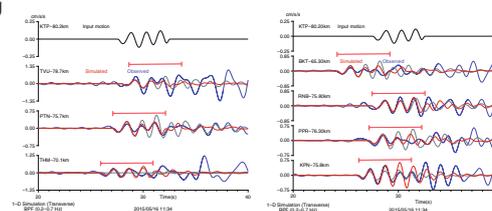
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## Abstract

The Himalayan collision zone experiences many seismic activities with large earthquakes occurring at certain time intervals. The damming of the proto-Bagmati River as a result of rapid mountain-building processes created a lake in the Kathmandu Valley that eventually dried out, leaving thick unconsolidated lacustrine deposits. Previous studies have shown that the sediments are ~600 m thick in the center. A location in a seismically active region, and the possible amplification of seismic waves due to thick sediments, have made Kathmandu Valley seismically vulnerable. It has suffered devastation due to earthquakes several times in the past. The development of the Kathmandu Valley into the largest urban agglomerate in Nepal has exposed a large population to seismic hazards. This vulnerability was apparent during the Gorkha Earthquake (Mw7.8) on April 25, 2015, when the main shock and ensuing aftershocks claimed more than 1700 lives and nearly 13% of buildings inside the valley were completely damaged. Preparing safe and up-to-date building codes to reduce seismic risk requires a thorough study of ground motion amplification. Characterizing subsurface velocity structure is a step toward achieving that goal. We used the records from an array of strong-motion accelerometers installed by Hokkaido University and Tribhuvan University to construct 1-D velocity models of station sites by forward modeling of low-frequency S-waves. Filtered records (0.1–0.5 Hz) from one of the accelerometers installed at a rock site during a moderate-sized (mb4.9) earthquake on August 30, 2013, and three moderate-sized (Mw5.1, Mw5.1, and Mw5.5) aftershocks of the 2015 Gorkha Earthquake were used as input motion for modeling of low-frequency S-waves. We consulted available geological maps, cross-sections, and borehole data as the basis for initial models for the sediment sites. This study shows that the basin has an undulating topography and sediment sites have deposits of varying thicknesses, from 155 to 440 m. These models also show high velocity contrast at the bedrock depth which results in significant wave amplification.

**Keywords:** 1-D simulation, Velocity model, Propagator matrix, Diffused field theory, Kathmandu Valley



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# Deriving amplification factors from simple site parameters using generalized regression neural networks: implications for relevant site proxies

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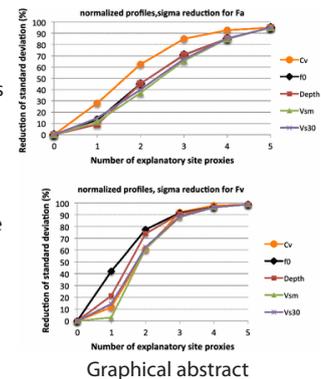
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## Abstract

Most modern seismic codes account for site effects using an amplification factor (AF) that modifies the rock acceleration response spectra in relation to a "site condition proxy," i.e., a parameter related to the velocity profile at the site under consideration. Therefore, for practical purposes, it is interesting to identify the site parameters that best control the frequency-dependent shape of the AF. The goal of the present study is to provide a quantitative assessment of the performance of various site condition proxies to predict the main AF features, including the often used short- and mid-period amplification factors,  $F_0$  and  $F_v$ , proposed by Borchardt (in *Earthq Spectra* 10:617–653, 1994). In this context, the linear, viscoelastic responses of a set of 858 actual soil columns from Japan, the USA, and Europe are computed for a set of 14 real accelerograms with varying frequency contents. The correlation between the corresponding site-specific average amplification factors and several site proxies (considered alone or as multiple combinations) is analyzed using the generalized regression neural network (GRNN). The performance of each site proxy combination is assessed through the variance reduction with respect to the initial amplification factor variability of the 858 profiles. Both the whole period range and specific short- and mid-period ranges associated with the Borchardt factors  $F_0$  and  $F_v$  are considered. The actual amplification factor of an arbitrary soil profile is found to be satisfactorily approximated with a limited number of site proxies (4–6). As the usual code practice implies a lower number of site proxies (generally one, sometimes two), a sensitivity analysis is conducted to identify the "best performing" site parameters. The best one is the overall velocity contrast between underlying bedrock and minimum velocity in the soil column. Because these are the most difficult and expensive parameters to measure, especially for thick deposits, other more convenient parameters are preferred, especially the couple ( $V_{330r}$ ,  $f_0$ ) that leads to a variance reduction in at least 60%. From a code perspective, equations and plots are provided describing the dependence of the short- and mid-period amplification factors  $F_0$  and  $F_v$  on these two parameters. The robustness of the results is analyzed by performing a similar analysis for two alternative sets of velocity profiles, for which the bedrock velocity is constrained to have the same value for all velocity profiles, which is not the case in the original set.

**Keywords:** 1D linear site response, Site proxies, Amplification factors, Neural network



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# Surface wave group velocity in the Osaka sedimentary basin, Japan, estimated using ambient noise cross-correlation functions

Kimiyuki Asano\*, Tomotaka Iwata, Haruko Sekiguchi, Kazuhiro Somei, Ken Miyakoshi, Shin Aoi and Takashi Kunugi

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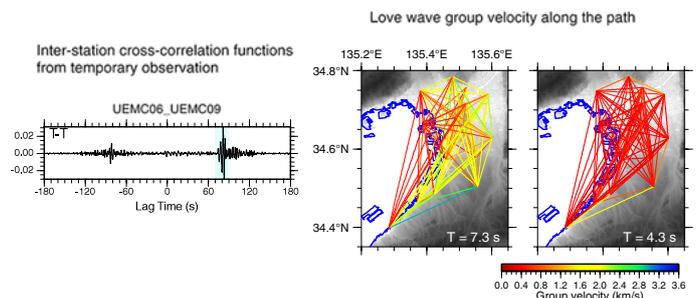
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## Abstract

Inter-station cross-correlation functions estimated using continuous ambient noise or microtremor records were used to extract the seismic wave propagation characteristics of the Osaka sedimentary basin, Japan. Temporary continuous observations were conducted at 15 sites in the Osaka basin between 2011 and 2013. The data were analyzed using seismic interferometry. The target period range was 2–8 s. Cross-correlations between all of the possible station pairs were calculated and stacked to produce a year-long data set, and Rayleigh wave signals in the vertical and radial components and Love wave signals in the transverse component were identified from the results. Simulation of inter-station Green's functions using the finite difference method was conducted to check the performance of the current three-dimensional velocity structure model. The measured time lag between the observed and theoretical Green's functions was less than 2 s for most station pairs, which is less than the wave period of interest in the target frequency range. Group velocity tomography was applied to group delay times estimated by means of multiple filter analysis. The estimated group velocities for longer periods of 5–8 s exhibited spatial variation within the basin, which is consistent with the bedrock depth distribution; however, the group velocities for shorter periods of 2–3 s were almost constant over the studied area. The waveform and group velocity information obtained by seismic interferometry analysis can be useful for future reconstruction of a three-dimensional velocity structure model in the Osaka basin.

**Keywords:** Osaka sedimentary basin, Velocity structure model, Seismic interferometry, Surface wave, Group velocity



Graphical abstract

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# The impact evaluation of soil liquefaction on low-rise building in the Meinong earthquake

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## Abstract

This paper presents major preliminary observations on the liquefaction-induced damages in the Meinong earthquake ( $M_L = 6.4$ ). The severe damages to buildings centered on Huian and Sanmin Streets in Tainan City where the places were reclaimed fish or farm ponds with poor construction quality from many decades ago. To better understand the effect due to the soil liquefaction at these sites, the information provided by the in situ 13 Standard Penetration Test boreholes and 5 Cone Penetration Test soundings accompanying with the PGAs derived from the near seismographs was used to conduct the soil liquefaction evaluation by the Seed method (Seed et al. in *J Geotech Eng ASCE* 111(12):1425–1445, 1985) when subject to the Meinong earthquake. The liquefaction potential index (LPI) was then evaluated accordingly. From the results, it was found that the estimated damage severity was not consistent to the field conditions if the local site effect was not taken into account. To better reflect the site response in such sites, the sites' PGAs in the PGA contour map were multiplied by 1.5 times to quantify the amplification effects due to the soft geological condition. In addition, the PGAs based on other simple approaches were evaluated as well for comparison. Besides, the effects of fines content and magnitude scaling factor were also discussed in this paper. After that, several common simplified methods were also used to calculate the LPI when subject to the Meinong earthquake in order to evaluate the applicability of these simplified methods.

**Keywords:** Liquefaction, Building damage, Uncertainty, Meinong earthquake

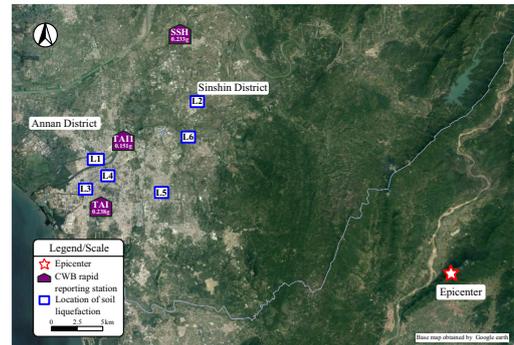


Fig. 1

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# Five parameters for the evaluation of the soil nonlinearity during the Ms8.0 Wenchuan Earthquake using the HVSR method

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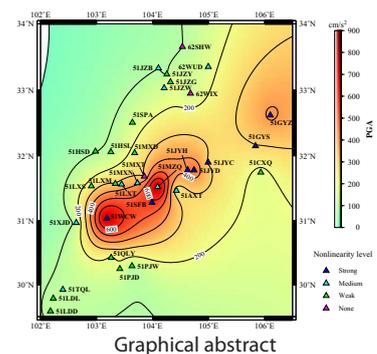
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## Abstract

The consideration of soil nonlinearity is important for the accurate estimation of the site response. To evaluate the soil nonlinearity during the 2008 Ms8.0 Wenchuan Earthquake, 33 strong-motion records obtained from the main shock and 890 records from 157 aftershocks were collected for this study. The horizontal-to-vertical spectral ratio (HVSR) method was used to calculate five parameters: the ratio of predominant frequency ( $RF_p$ ), degree of nonlinearity (DNL), absolute degree of nonlinearity (ADNL), frequency of nonlinearity ( $f_{NL}$ ), and percentage of nonlinearity (PNL). The purpose of this study was to evaluate the soil nonlinearity level of 33 strong-motion stations and to investigate the characteristics, performance, and effective usage of these five parameters. Their correlations with the peak ground acceleration (PGA), peak ground velocity (PGV), average uppermost 30-m shear-wave velocity ( $V_{S30}$ ), and maximum amplitude of HVSR ( $A_{max}$ ) were investigated. The results showed that all five parameters correlate well with PGA and PGV. The DNL, ADNL, and PNL also show a good correlation with  $A_{max}$ , which means that the degree of soil nonlinearity not only depends on the ground-motion amplitude (e.g., PGA and PGV) but also on the site condition. The  $f_{NL}$  correlates with PGA and PGV but shows no correlation with either  $A_{max}$  or  $V_{S30}$ , implying that the frequency width affected by the soil nonlinearity predominantly depends on the ground-motion amplitude rather than the site condition. At 16 of the 33 stations analyzed in this study, the site response showed evident (i.e., strong and medium) nonlinearity during the main shock of the Wenchuan Earthquake, where the ground-motion level was almost beyond the threshold of  $PGA > 200 \text{ cm/s}^2$  or  $PGV > 15 \text{ cm/s}$ . The site response showed weak and no nonlinearity at the other 14 and 3 stations. These results also confirm that  $RF_p$ , DNL, ADNL, and PNL are effective in identifying the soil nonlinearity behavior. The identification results vary for different parameters because each parameter has individual features. The performance of the PNL was better than that of DNL and ADNL in this case study. The thresholds of ADNL and PNL are proposed to be 2.0 and 7%, respectively.

**Keywords:** Wenchuan Earthquake, Soil nonlinearity, Site response, HVSR method, DNL, PGA, PGV,  $V_{S30}$



Graphical abstract

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# Analysis of rotation sensor data from the SINAPS@ Kefalonia (Greece) post-seismic experiment—link to surface geology and wavefield characteristics

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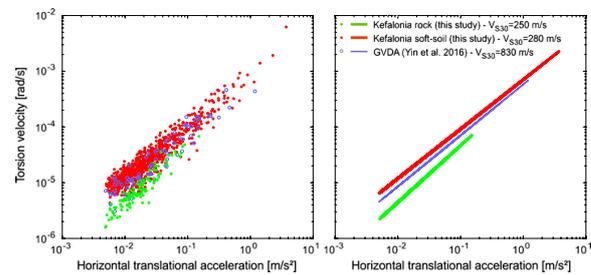
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## Abstract

Although rotational seismology has progressed in recent decades, the links between rotational ground motion and site soil conditions are poorly documented. New experiments were performed on Kefalonia Island (Greece) following two large earthquakes ( $M_W = 6.0$ ,  $M_W = 5.9$ ) in early 2014 on two well-characterized sites (soft soil,  $V_{530} \sim 250$  m/s; rock,  $V_{530} \sim 830$  m/s,  $V_{530}$  being harmonic average shear-wave velocity between 0 and 30 m depth). These earthquakes led to large six-component (three translations and three rotations) datasets of hundreds of well-recorded events. The relationship between peak translational acceleration versus peak rotational velocity is found sensitive to the site conditions mainly for the rotation around the vertical axis (torsion; dominated by Love waves): the stiffer the soil, the lower the torsion, for a given level of translational acceleration. For rotation around the horizontal axes (rocking; dominated by Rayleigh waves), this acceleration/rotation relationship exhibits much weaker differences between soft and rock sites. Using only the rotation sensor, an estimate of the Love-to-Rayleigh energy ratios could be carried out and provided the same results as previous studies that have analyzed the Love- and Rayleigh-wave energy proportions using data from translational arrays deployed at the same two sites. The coupling of translational and rotational measurements appears to be useful, not only for direct applications of engineering seismology, but also to investigate the composition of the wavefield, while avoiding deployment of dense arrays. The availability of new, low-noise rotation sensors that are easy to deploy in the field is of great interest and should extend the use of rotation sensors and expand their possible applications.

**Keywords:** Rotational seismology, Wavefield characteristics,  $V_{530}$ , Site effects, Love wave, Rayleigh wave



Graphical abstract

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# On the seismic response of instable rock slopes based on ambient vibration recordings

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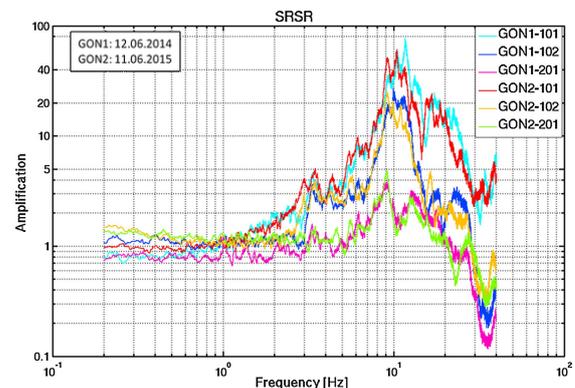
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## Abstract

Rock slope failures can lead to huge human and economic loss depending on their size and exact location. Reasonable hazard mitigation requires thorough understanding of the underlying slope driving mechanisms and its rock mass properties. Measurements of seismic ambient vibrations could improve the characterization and detection of rock instabilities since there is a link between seismic response and internal structure of the unstable rock mass. An unstable slope near the village Gondo has been investigated. The unstable part shows strongly amplified ground motion with respect to the stable part of the rock slope. The amplification values reach maximum factors of 70. The seismic response on the instable part is highly directional and polarized. Re-measurements have been taken 1 year later showing exactly the same results as the original measurements. Neither the amplified frequencies nor the amplification values have changed. Therefore, ambient vibration measurements are repeatable and stay the same, if the rock mass has not undergone any significant change in structure or volume, respectively. Additionally, four new points have been measured during the re-measuring campaign in order to better map the border of the instability.

**Keywords:** Ambient vibrations, Instable rock slopes, Site amplification



Graphical abstract

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# $V_{530}$ , slope, $H_{800}$ and $f_0$ : performance of various site-condition proxies in reducing ground-motion aleatory variability and predicting nonlinear site response

Boumediène Derras\*, Pierre-Yves Bard and Fabrice Cotton

*Earth, Planets and Space* 2017, **69**:133 DOI:10.1186/s40623-017-0718-z

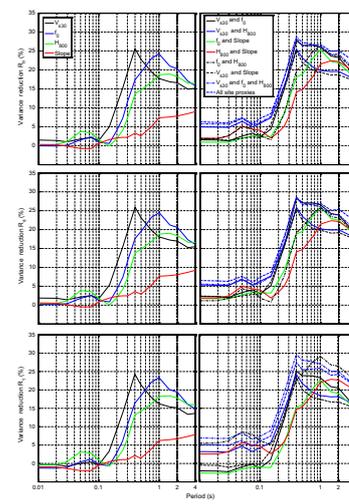
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## Abstract

The aim of this paper is to investigate the ability of various site-condition proxies (SCPs) to reduce ground-motion aleatory variability and evaluate how SCPs capture nonlinearity site effects. The SCPs used here are time-averaged shear-wave velocity in the top 30 m ( $V_{530}$ ), the topographical slope (slope), the fundamental resonance frequency ( $f_0$ ) and the depth beyond which  $V_s$  exceeds 800 m/s ( $H_{800}$ ). We considered first the performance of each SCP taken alone and then the combined performance of the 6 SCP pairs [ $V_{530}$ - $f_0$ ], [ $V_{530}$ - $H_{800}$ ], [ $f_0$ -slope], [ $H_{800}$ -slope], [ $V_{530}$ -slope] and [ $f_0$ - $H_{800}$ ]. This analysis is performed using a neural network approach including a random effect applied on a KiK-net subset for derivation of ground-motion prediction equations setting the relationship between various ground-motion parameters such as peak ground acceleration, peak ground velocity and pseudo-spectral acceleration PSA ( $T$ ), and  $M_w$ ,  $R_{JB}$ , focal depth and SCPs. While the choice of SCP is found to have almost no impact on the median ground-motion prediction, it does impact the level of aleatory uncertainty.  $V_{530}$  is found to perform the best of single proxies at short periods ( $T < 0.6$  s), while  $f_0$  and  $H_{800}$  perform better at longer periods; considering SCP pairs leads to significant improvements, with particular emphasis on [ $V_{530}$ - $H_{800}$ ] and [ $f_0$ -slope] pairs. The results also indicate significant nonlinearity on the site terms for soft sites and that the most relevant loading parameter for characterising nonlinear site response is the "stiff" spectral ordinate at the considered period.

**Keywords:** Aleatory variability, Site-condition proxies, KiK-net, Neural networks, GMPE, Nonlinear site response



Graphical abstract

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# Application of a simplified calculation for full-wave microtremor $H/V$ spectral ratio based on the diffuse field approximation to identify underground velocity structures

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*Earth, Planets and Space* 2017, **69**:162 DOI:10.1186/s40623-017-0746-8

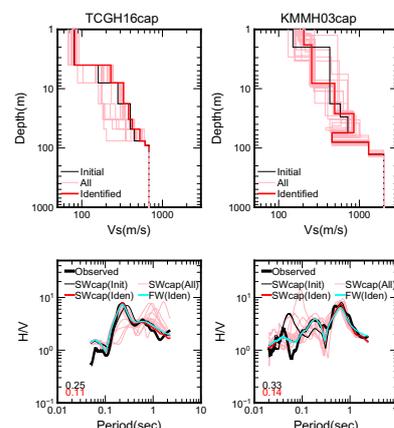
Received: 21 December 2016, Accepted: 15 November 2017, Published: 4 December 2017



## Abstract

Under the diffuse field approximation, the full-wave (FW) microtremor  $H/V$  spectral ratio ( $H/V$ ) is modeled as the square root of the ratio of the sum of imaginary parts of the Green's function of the horizontal components to that of the vertical one. For a given layered medium, the FW  $H/V$  can be well approximated with only surface waves (SW)  $H/V$  of the "cap-layered" medium which consists of the given layered medium and a new larger velocity half-space (cap layer) at large depth. Because the contribution of surface waves can be simply obtained by the residue theorem, the computation of SW  $H/V$  of cap-layered medium is faster than that of FW  $H/V$  evaluated by discrete wavenumber method and contour integration method. The simplified computation of SW  $H/V$  was then applied to identify the underground velocity structures at six KiK-net strong-motion stations. The inverted underground velocity structures were used to evaluate FW  $H/V$ s which were consistent with the SW  $H/V$ s of corresponding cap-layered media. The previous study on surface waves  $H/V$ s proposed with the distributed surface sources assumption and a fixed Rayleigh-to-Love waves amplitude ratio for horizontal motions showed a good agreement with the SW  $H/V$ s of our study. The consistency between observed and theoretical spectral ratios, such as the earthquake motions of  $H/V$  spectral ratio and spectral ratio of horizontal motions between surface and bottom of borehole, indicated that the underground velocity structures identified from SW  $H/V$  of cap-layered medium were well resolved by the new method.

**Keywords:** Diffuse field approximation, Microtremor  $H/V$  spectral ratio, Full-wave, Surface waves, Underground velocity structures



Graphical abstract

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# Difference of horizontal-to-vertical spectral ratios of observed earthquakes and microtremors and its application to S-wave velocity inversion based on the diffuse field concept

Hiroshi Kawase\*, Yuta Mori and Fumiaki Nagashima

*Earth, Planets and Space* 2018, **70**:1 DOI:10.1186/s40623-017-0766-4

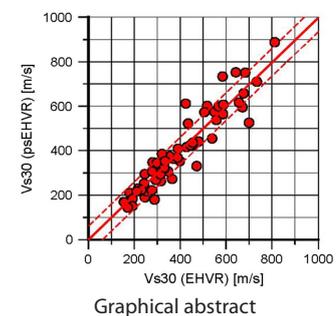
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## Abstract

We have been discussing the validity of using the horizontal-to-vertical spectral ratios (HVRs) as a substitute for S-wave amplifications after Nakamura first proposed the idea in 1989. So far a formula for HVRs had not been derived that fully utilized their physical characteristics until a recent proposal based on the diffuse field concept. There is another source of confusion that comes from the mixed use of HVRs from earthquake and microtremors, although their wave fields are hardly the same. In this study, we compared HVRs from observed microtremors (MHVR) and those from observed earthquake motions (EHVR) at one hundred K-NET and KiK-net stations. We found that MHVR and EHVR share similarities, especially until their first peak frequency, but have significant differences in the higher frequency range. This is because microtremors mainly consist of surface waves so that peaks associated with higher modes would not be prominent, while seismic motions mainly consist of upwardly propagating plain body waves so that higher mode resonances can be seen in high frequency. We defined here the spectral amplitude ratio between them as EMR and calculated their average. We categorize all the sites into five bins by their fundamental peak frequencies in MHVR. Once we obtained EMRs for five categories, we back-calculated EHVRs from MHVRs, which we call pseudo-EHVRs (pEHVR). We found that pEHVR is much closer to EHVR than MHVR. Then we use our inversion code to invert the one-dimensional S-wave velocity structures from EHVRs based on the diffuse field concept. We also applied the same code to pEHVRs and MHVRs for comparison. We found that pEHVRs yield velocity structures much closer to those by EHVRs than those by MHVRs. This is natural since what we have done up to here is circular except for the average operation in EMRs. Finally, we showed independent examples of data not used in the EMR calculation, where better ground structures were successfully identified from pEHVRs again. Thus we proposed here a simple empirical method to estimate S-wave velocity structures using single-station microtremor records, which is the most cost-effective method to characterize the site effects.

**Keywords:** Site effect, Subsurface structure, Seismological bedrock, Horizontal-to-vertical ratio, Hybrid heuristic search, S-wave, P-wave



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# Assessment of nonlinear site response at ocean bottom seismograph sites based on S-wave horizontal-to-vertical spectral ratios: a study at the Sagami Bay area K-NET sites in Japan

Yadab P. Dhakal\*, Shin Aoi, Takashi Kunugi, Wataru Suzuki and Takeshi Kimura

*Earth, Planets and Space* 2017, **69**:29 DOI:10.1186/s40623-017-0615-5

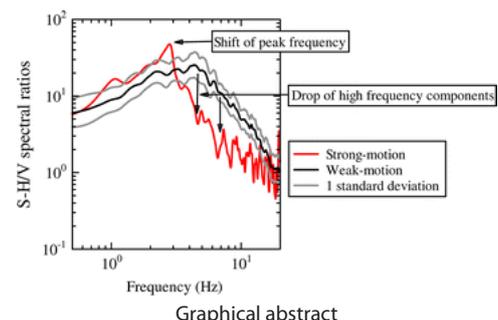
Received: 3 October 2016, Accepted: 2 February 2017, Published: 8 February 2017



## Abstract

We analyzed S-wave horizontal-to-vertical (S-H/V) spectral ratios at six ocean bottom seismograph (OBS) sites of K-NET located in the Sagami Bay area of Japan for nonlinear site responses. The degree of nonlinearity was computed by comparing the S-H/V spectral ratios for strong motions ( $\text{PGA} \geq 20 \text{ cm/s}^2$ ) with those for weak motions ( $\text{PGA} < 20 \text{ cm/s}^2$ ). Our analyses, which showed that the weak-motion S-H/V spectral ratios differ from site to site, indicate that the underlying site geology is not uniform at the OBS sites. It was found that the threshold PGA causing a nonlinear site response is generally different from site to site. Recordings having horizontal PGAs greater than about 50–150  $\text{cm/s}^2$  display clear signatures of nonlinear site effects, i.e., the shift of predominant frequencies to lower ones and/or the decrease in high-frequency spectral ratios. We also found that the degree of nonlinearity is generally larger at the OBS sites due to the smaller threshold motions that cause a nonlinear site response compared with the available data at land sites. The above findings suggest the possibility of a widespread nonlinear site response at the OBS sites for offshore earthquakes with a large magnitude. However, frequencies lower than about 2 Hz are not affected by the nonlinear site response in the analyzed data ranges ( $\text{PGA} < 467 \text{ cm/s}^2$ ). These results indicate the need for careful utilization of recorded strong motions at OBS sites for applications such as real-time ground motion predictions as front detections.

**Keywords:** Ocean bottom seismograph, Nonlinear site response, Horizontal-to-vertical spectral ratio, Sagami Bay



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# Effects of subsurface structures of source regions on long-period ground motions observed in the Tokyo Bay area, Japan

Tomiichi Uetake

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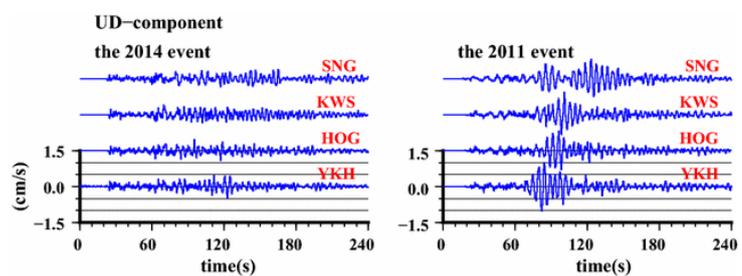
Received: 21 December 2016, Accepted: 16 May 2017, Published: 22 May 2017



## Abstract

We compared the long-period ground motion observed in the Tokyo Bay area during two shallow M6.7 earthquakes that occurred in northern Nagano Prefecture, Japan, on March 12, 2011, and November 22, 2014. The magnitudes, focal depths, and source mechanisms of these events were almost identical, but their seismograms were quite different. Significant long-period later arrivals with a predominant period of 5 s were recognized in the velocity traces of the 2011 event, but there were no such remarkable later arrivals in the 2014 event traces. The ground motions at stations located outside the basin area were studied as incident waves to the Kanto Basin. A large wave packet with a predominant period of 5 s was recognized in the velocity traces of the 2011 event, but there was no significant wave packet in the 2014 event traces. Based on particle motion, this wave packet was hypothesized to be a Rayleigh wave. The source regions of the two events have quite different subsurface structures. The different characteristics in long-period ground motion in the Tokyo Bay area during the two events were due to different Rayleigh wave excitations in the source regions.

**Keywords:** Long-period ground motion, Rayleigh wave, Velocity structure, Source region, Kanto Basin



Graphical abstract

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# Modeling and inversion of the microtremor $H/V$ spectral ratio: physical basis behind the diffuse field approach

Francisco J. Sánchez-Sesma

*Earth, Planets and Space* 2017, **69**:92 DOI:10.1186/s40623-017-0667-6

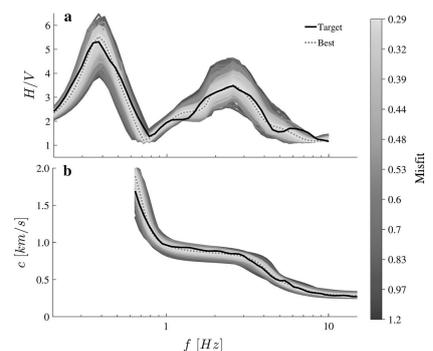
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## Abstract

Microtremor  $H/V$  spectral ratio (MHVSR) has gained popularity to assess the dominant frequency of soil sites. It requires measurement of ground motion due to seismic ambient noise at a site and a relatively simple processing. Theory asserts that the ensemble average of the autocorrelation of motion components belonging to a diffuse field at a given receiver gives the directional energy densities (DEDs) which are proportional to the imaginary parts of the Green's function components when both source and receiver are the same point and the directions of force and response coincide. Therefore, the MHVSR can be modeled as the square root of  $2 \times \text{Im}G_{11}/\text{Im}G_{33}$ , where  $\text{Im}G_{11}$  and  $\text{Im}G_{33}$  are the imaginary parts of Green's functions at the load point for the horizontal (sub-index 1) and vertical (sub-index 3) components, respectively. This connection has physical implications that emerge from the duality DED force and allows understanding the behavior of the MHVSR. For a given model, the imaginary parts of the Green's functions are integrals along a radial wavenumber. To deal with these integrals, we have used either the popular discrete wavenumber method or the Cauchy's residue theorem at the poles that account for surface waves normal modes giving the contributions due to Rayleigh and Love waves. For the retrieval of the velocity structure, one can minimize the weighted differences between observations and calculated values using the strategy of an inversion scheme. In this research, we used simulated annealing but other optimization techniques can be used as well. This last approach allows computing separately the contributions of different wave types. An example is presented for the mouth of Andarax River at Almería, Spain.

**Keywords:** Ambient seismic noise, Site effects, Diffuse fields,  $H/V$  spectral ratio



Graphical abstract

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# Effect of the surface geology on strong ground motions due to the 2016 Central Tottori Earthquake, Japan

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## Abstract

On October 21, 2016, an earthquake with Japan Meteorological Agency (JMA) magnitude 6.6 hit the central part of Tottori Prefecture, Japan. This paper demonstrates two notable effects of the surface geology on strong ground motions due to the earthquake. One is a predominant period issue observed over a large area. A seismic intensity of 6 lower on the JMA scale was registered at three sites in the disaster area. However, the peak ground acceleration ranged from 0.3 to 1.4 G at the three sites because of the varying peak periods of observed strong ground motions. The spectral properties of the observations also reflect the damage around the sites. Three-component microtremors were observed in the area; the predominant ground period distributions based on horizontal to vertical spectral ratios were provided by the authors. The peak periods of the strong motion records agree well with predominant periods estimated from microtremor observations at a rather hard site; however, the predominant periods of the microtremors are slightly shorter than those of the main shock at the other two soft sites. We checked the nonlinear effect at the sites by comparing the site responses to small events and the main shock. The peak periods of the main shock were longer than those of the weak motions at the sites. This phenomenon indicates a nonlinear site effect due to large ground motions caused by the main shock. A horizontal component of the accelerogram showed rather pulsating swings that indicate cyclic mobility behavior, especially at a site close to a pond shore; ground subsidence of ~20 cm was observed around the site. The peak periods of weak motions agree well with those of the microtremor observations. This implies an important issue that the predominant periods estimated by microtremors are not sufficient to estimate the effect of surface geology for disaster mitigation. We have to estimate the predominant periods under large ground motions considering the nonlinear site response of soft sediment sites.

**Keywords:** Strong ground motion, Ground predominant period, Microtremor observation, H/V spectrum, Nonlinear effect

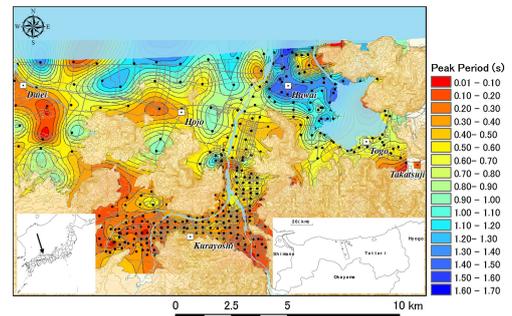


Fig. 1

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# Information for Contributors

## *General*

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7. References must follow the Springer Basic style.

## *Correspondence*

If you have any questions, please contact [editorial@earth-planets-space.com](mailto:editorial@earth-planets-space.com).

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