論 文 の 内 容 の 要 旨

論文題目　Long-Period Ground Motion Simulations using the Ambient Seismic Field
（地震波干渉法による長周期地震動シミュレーション）

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Seismic waves generated by earthquakes have the potential to damage human-made structures and affect a large population worldwide. Japan, which is located at the junction of several tectonic plates, is under the constant threat of both subduction and crustal seismic events. In this context, the prediction of earthquake ground motions is critical to assess seismic hazard and prevent disasters. In this thesis, we focus on the long-period component of the ground motions (≥ 1 s) which became a source of primary concern with the ever-increasing construction of large-scale structures, such as high-rise buildings, oil storage tanks, and suspension bridges.

Ground shaking is generally predicted using ground motion prediction equations (GMPEs) that are derived from records of past earthquakes. However, these equations suffer from a shortage of data for large earthquakes at short distances and are limited in their capability to accurately predict local site effects. Physics-based methods, which simulate the whole earthquake process from the source to a given site, have also been developed. However, such simulations require accurate velocity models and large computational resources to generate realistic waveforms.

Over the last decade, seismic interferometry has revolutionized seismology. This technique allows to extract the response of the Earth to a point force, called Green's function, between a pair of seismic stations that continuously record the ambient seismic field. Reliable phase and amplitude of Green's functions can be extracted through the deconvolution method by regarding seismometers located close to earthquake hypocenters as virtual sources and other stations as receivers. We take advantage of the ambient seismic field continuously recorded by thousands of seismometers in Japan to simulate long-period ground motions generated by different kinds of earthquakes.

We first demonstrate that after amplitude calibration, the extracted Green's functions can be used to simulate the long-period ground motions of a shallow $M_w$ 5.0 subduction earthquake that occurred along the Nankai Trough. We use an offshore ocean bottom seismometer located in the vicinity of the earthquake epicenter as the virtual source and onshore stations as receivers. We show that the extracted offshore-onshore Green's functions can be used to accurately simulate the long-period ground motions generated by the offshore event. We also find that the distribution of the 5% damped pseudovelocity responses computed from the earthquake and Green's function waveforms have similar amplifications patterns.

Local velocity structures, such as sedimentary basins, can significantly affect the propagation of seismic waves through the Earth. We investigate the propagation characteristics of seismic waves across the Kanto basin, Japan, using Green's functions extracted from the ambient seismic field. We use two stations situated on the eastern and southern edges of the basin as virtual sources and the stations of the Metropolitan Seismic Observation network (MeSO-net), as receivers. Using dense seismometers aligned along two straight lines with the virtual sources, we find that several types of waves can be recovered, each with different sensitivities to the layers that compose the basin. We then compare the extracted Green's functions to the seismic waves generated by two moderate $M_w$ 4–5 shallow earthquakes that occurred close to the virtual sources. For these two events, long-period ground motions are well simulated. This demonstrates all the power of dense networks that continuously record the ambient seismic field for assessing seismic hazard at high spatial resolution in metropolitan areas.

Large ($M_w > 6$) earthquakes have the potential to generate damaging long-period ground motions. For such events, the point source hypothesis that is made for moderate earthquakes is no longer valid and an extended rupture needs to be taken into account. We focus on the 2008 $M_w$ 6.9 Iwate-Miyagi Nairiku earthquake that occurred in the Tohoku region. We extract Green's functions between stations located in the vicinity of the mainshock fault plane and dozens of stations that are regarded as receivers. We calibrate the amplitude of the extracted Green's functions with the records of a $M_w$ 5.0 aftershock which has a reverse faulting focal mechanism similar to the one of the mainshock. We use scaling relations between small and large earthquakes to construct simple finite source models that have similar parameters to the ones retrieved by source inversion studies. We compare the simulated waveforms obtained by the different source models and find a general good agreement with the observed records at long-periods. This study supports the fact that the ambient seismic field can be used together with simple finite source models to assess the seismic hazard related to large earthquakes.

We finally show that the deconvolution method can be used not only to simulate ground motions, but also to predict the motion of buildings during earthquakes. In the Tokyo metropolitan area, several large scale structures have been equipped with seismic sensors. We extract the response of a telecommunication tower located in the Kanagawa prefecture from earthquake data and ambient vibrations recorded at different heights of the structure. We first estimate several characteristics of the waves propagating in the structure, such as their velocity, frequency content, and attenuation. Using Green's functions extracted from the ambient seismic field, we simulate the long-period ground motions of a $M_w$ 4.1 event which occurred in the Hakone region. We construct a finite source model that is used together with the extracted Green's functions to predict the ground motions of a hypothetical $M_w$ 6.5 earthquake that could occur in the same area along the Sagami Trough. Simulated and predicted ground motions are finally convolved with the tower response to simulate the building motions that could be caused by such moderate and large events. The integrated simulation from earthquake source to building motion shows promising results that might help to mitigate seismic risk.