IMAGING AND MONITORING SUBSURFACE STRUCTURE BY USING CROSS-CORRELATION OF SEISMIC AMBIENT NOISE

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論 文 名：**IMAGING AND MONITORING SUBSURFACE STRUCTURE BY USING CROSS-CORRELATION OF SEISMIC AMBIENT NOISE**
（雑微動を用いた地下構造のイメージングとモニタリング）

区　　分　：甲

論　文　内　容　の　要　旨

Constructing an accurate underground structure model and monitoring the underground state is essential to realize a society prepared for natural disasters and enables sustainable development. In this study, I have conducted several studies about both imaging and monitoring subsurface structures using ambient seismic noise generated from atmospheric, oceanic, and other turbulent flows and social activities of people. The approach using seismic ambient noise is highly versatile due to the simple procedure of this method, the constant presence of the ambient seismic noise, and the developm ent permanent high-quality seismic network in Japan. Improving this versatile approach is important to develop a practica l system of imaging and monitoring subsurface structure. Developing a practical system accelerates the realization of a resilient and sustainable society. The details of the background, motivation, and purpose of this study are described in Chapter 1.

In Chapters 2 and 3, I studied imaging underground structures by using surface waves extracted from ambient seismic noise to improve the accuracy and resolution of estimated subsurface structures. In Chapter 2, I focused on improving the horizontal resolutions and visualized central Japan's subsurface S-wave velocity structure. The horizontal resolution was improved by combining the tomograph ic approach and higher frequency Rayleigh wave which is sensitive to smaller structures. I developed an application to automatically estimate the dispersion curve of the Rayleigh wave since the tomographic approach requires a mass of dispersion data. The estimated high-resolution three-dimensional S-wave velocity structure was used to interpret the complex geological structure of central Japan.

In Chapter 3, I focused on improving the vertical resolutions using higher modes of surface waves. Here I estimated the subsurface structure of the Kanto Basin, where thick sedimentary layers exist. Thick sediments and strong velocity contrast between sediments and basement rock induce higher modes of the surface wave. I estimated multimodal surface-wave dispersion curves by applying a method that can separate the phase velocities of fundamental and higher modes. The vertical resolution was improved by using higher modes of surface waves. The accuracy and precision of the estimated S-wave velocity model were significantly improved by at least 50% by using higher modes. Since each mode of surface waves has a different sensitivity to the S-wave velocity and thickness, including higher modes resulted in constraining the solutions such that they could be well estimated. The estimated S-wave velocity model using higher modes better explains the complex characteristics of seismic wave propagation, which cause significant damage when a large earthquake occurs.

In Chapter 4, I used ambient seismic noise to monitor the subsurface structures, taking advantage of the constant presence of the ambient seismic noise. The time-series of surface waves as a signal were extracted by calculating cross-correlations of ambient seismic noise each day. The state of the subsurface structure can be reflected through the seismic velocity of the surface wave, which propagates between two seismic stations. Since the seismic velocity change is too small to estimate from the direct part of the surface wave, I used scattered waves which follow the direct surface wave. Here, I revealed the change in the subsurface structure during the 2016 Kumamoto earthquake from the seismic velocity change. The velocity changes before and after the Kumamoto earthquake were estimated in many pairs of seismic stations, and the resultant velocity changes were mapped by averaging spatially. I observed a large decrease in velocity near the seismogenic fault after the Kumamoto earthquake. The largest velocity decrease was observed around the Aso volcano, which became active after the Kumamoto earthquake. These observations provide important knowledge of the relationship between earthquakes and the activities of volcanoes.

In Chapter 5, I focused on the use of ambient seismic noises generated from human activities, such as vibrations from traffic and constructions. Recently, these seismic noises are also used as the signals of geophysical explorations. This anthropogenic seismic noise is complex because many and an unspecified number of seismic sources exist. Anthropogenic seismic noise as a signal makes it possible to image and monitor the local subsurface structure by taking advantage of the existence of many seismic sources. Understanding the characteristics of anthropogenic seismic noise helps identify specific seismic sources which may be utilized as the signal of geophysical explorations. To understand the anthropogenic seismic noise, I monitored the magnitude of anthropogenic seismic noise and compared it to human activities during the COVID-19 pandemic. Although the outbreak of the COVID-19 has immensely impacted and restricted the routine lives of people worldwide, the large-scale restrictions on human activities during the pandemic also presented a rare opportunity to study the anthropogenic seismic noise because of the seismic sources are restricted. I investigated the variation in the magnitude of anthropogenic seismic noise in different periods and on different days of the week. In addition, since the estimated temporal variation showed clear seasonal variations, I modeled the seasonal variations by assuming a simple annual cycle based on the data of the past 2 years. I estimated corrected temporal variations of the noise level and found a clear relationship to people's economic and leisure activities. This finding also demonstrates that seismic noise can be used to monitor social activities.

In Chapter 6, I summarize the details of important findings of this study and discuss future developments. In this study, I developed applications for imaging and monitoring underground structures using ambient seismic noise. The geophysical exploration using ambient seismic noise is versatile due to the constant presence of signals. Our studies improved the resolution and accuracy of the versatile method using ambient seismic noise and developed the monitoring approach. These improved applications can contribute to realize a society prepared for natural disasters and enable sustainable development.