論　文　の　要　旨

題　目　　Prediction of Site Effects and Ground Motion Parameters through Deep Neural Networks Using Horizontal-to-Vertical Spectral Ratios
(水平/上下スペクトル比を用いた深層ニューラルネットワークによる地盤特性と地震動強さの予測に関する研究)

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Ground motion models (GMM) are key tools for predicting seismic ground motions in future earthquakes and are also critical for regional disaster planning and seismic-resistant building design. Seismic ground motion models are influenced by source characteristics, propagation path effects, and site effects (also known as site amplification factors, SAFs). SAFs play a significant role in controlling the amplitudes of seismic waves at the surface. SAFs have been generally assessed by theoretical approaches based on one-dimensional S-wave propagation assumption and/or empirical approaches based on long-term seismic observation records and generalized spectral inversion technique (GIT). Researchers have also explored SAF estimation methods based on horizontal-vertical spectral ratio (HVR) of earthquake and microtremor records. Recently, artificial intelligence technologies including deep neural network (DNN) have been significantly developed in various fields. Although the HVR and DNN techniques have enormous potential for easily assessing site effects, the applications of these techniques have not been fully discussed in earthquake engineering fields. This study proposes novel methodologies to evaluate SAFs and to predict seismic ground motion intensities by single site microtremor data based on the HVR technique and the DNN models. The study is structured into seven chapters, each addressing a specific aspect of the research.

Chapter 1 provided a comprehensive background on earthquake engineering, emphasizing the importance of accurate ground motion prediction and the critical role of site effects. It discusses the significance of HVRs in assessing site effects and outlines the objectives and structure of the dissertation. This chapter sets the stage by establishing the importance of predicting ground motion and understanding site effects using HVR.

Chapter 2 explored the first objective of the study, and developed a DNN model utilizing microtremor horizontal-to-vertical spectral ratios (MHVR) for predicting SAFs obtained by long-term seismic observation records and GIT. It details the data collection, model construction, and validation processes. The observed and estimated SAFs represent frequency-dependent amplification of S-waves from the seismic bedrock to ground surface. The MHVRs and SAFs obtained at Chugoku district, west Japan were analyzed in this chapter. The result shows that the DNN model demonstrated superior performance in estimating SAFs compared to traditional statistical methods, showcasing the potential of using MHVR data for site effects assessment. The developed DNN model does not require any hard-to-get data such as seismic velocity structures and damping models thus providing a significant cost-benefit.

Chapter 3 expanded on this foundation by incorporating transfer learning techniques to adapt the pre-trained DNN model for new regions with varying geological conditions It discusses the compilation of SAFs and MHVRs obtained at seismic observation sites in whole of Japan and the construction of the transfer learning model. The transfer learning model significantly improved the performance in estimating SAFs in data-limited areas, demonstrating the feasibility of extending the applicability of the DNN model beyond its initial training region.

Chapter 4 introduced a model to predict pseudo-earthquake HVR (pEHVR) from MHVR, addressing the challenge of obtaining reliable EHVR data in regions without direct seismic observations. It discusses the comparison between MHVR and EHVR, model construction, and validation. The model successfully predicted pEHVR from MHVR with high accuracy. Future research should focus on improving high-frequency predictions and expanding the dataset to enhance generalizability.

Chapter 5 proposed the DNN model for predicting seismic ground motion parameters such as peak ground accelerations, peak ground velocities and period-dependent spectral accelerations using EHVRs. This chapter utilized the seismic ground motion database developed by National Research Institute for Earth Science and Disaster Resilience and the EHVR database at seismic observation sites in Japan. It integrates EHVR into existing ground motion prediction equations to improve prediction accuracy. The DNN model incorporating EHVR outperformed traditional GMMs based on site condition proxies such as average S-wave velocities in upper 30m depth (Vs30s) in predicting ground motion parameters, particularly for spectral amplitudes and their shapes. This chapter also discussed the application of pEHVRs obtained from MHVRs in predicting the ground motion parameters. The availability of reliable EHVR data and potential data leakage are limitations that need addressing in future research.

Chapter 6 summarized the findings of the previous chapters and discusses potential areas for future research. The research demonstrated the effectiveness of using HVR data for seismic risk assessment and ground motion prediction. Future work should focus on improving prediction accuracy, validating the models in diverse geological settings, and exploring the integration of additional seismic features to enhance model robustness.