Generative Adversarial Networks for Ground Motion Augmentation with the Capability to Control Pseudo-Spectral Acceleration and Significant Durations

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1. Introduction

The influence of ground motion duration on liquefaction and slope stability is well-recognized. Even within the same intensity level, variations in duration can impact the structural collapse capacities (Raghunandan & Liel, 2013). Modern infrastructure developments further complicate this issue by increasing vulnerabilities, resulting in more diverse and severe earthquake damage.

Generating substantial amounts of ground motion time history data with adjustable parameters can help address uncertainties beyond the constraints of existing recordings. However, incorporating ground motion intensities and detailed duration segments as variables for large-scale data generation still requires further research. In response, this study presents Generative Adversarial Network, GAN (Goodfellow et al., 2014)-based models capable of generating multiple accelerograms with controllable significant durations and spectral accelerations. This approach is expected to provide exploration flexibility and support comprehensive evaluations across diverse scenarios, advancing earthquake risk assessment.

2. Methods

The training dataset comprised seismic accelerograms along with their 5% damped Pseudo-Spectral Accelerations (PSAs) and significant durations corresponding to 5–35%, 35–65%, and 65–95% intervals (i.e., $D_{5–35}$, $D_{35–65}$, and $D_{65–95}$). The acceleration time series in both the east-west and north-south directions were obtained from the seismograph network of Japan, Kyoshin Network, i.e., K-NET (National Research Institute for Earth Science and Disaster Resilience, 2019).

Traditional GAN often encounters vanishing gradients. To enhance stability and parameter conditioning, we combined the concepts of Wasserstein GAN with gradient penalty (Gulrajani et al., 2017) and Conditional GAN (Mirza & Osindero, 2014).

3. Results and discussion

Two GAN-based generative models were developed: one conditioned on PSA and the other on the design spectrum. These models produce large volumes of accelerograms, with the amount determined by the desired number of sets, each consisting of a latent vector drawn from a Gaussian distribution and conditional information (i.e., PSA, $D_{5–35}$, $D_{35–65}$, and $D_{65–95}$). We assessed the performance of the generator in producing accelerograms consistent with the given input, using 50 samples generated with fixed conditional input values and varying latent vectors.

Two cases are presented in Figs. 1 and 2: the first illustrates the PSA-based model, while the second demonstrates the design spectrum-based model. Each figure illustrates (a) three generated samples (Sample^{G}), (b) PSA comparisons, where $\mathrm{Samples}^{G}$ represents PSAs from 50 generated samples, Mean^{G} denotes the mean PSA of $\mathrm{Samples}^{G}$, and Best^{G} indicates the PSA with the lowest Root Mean Squared Error (RMSE) compared to the input; and (c) comparisons of three significant duration components, presenting the values of input and Best^{G}, and the range of values from $\mathrm{Samples}^{G}$. The sample corresponding to Best^{G} is displayed in the uppermost panel of (a). The visual

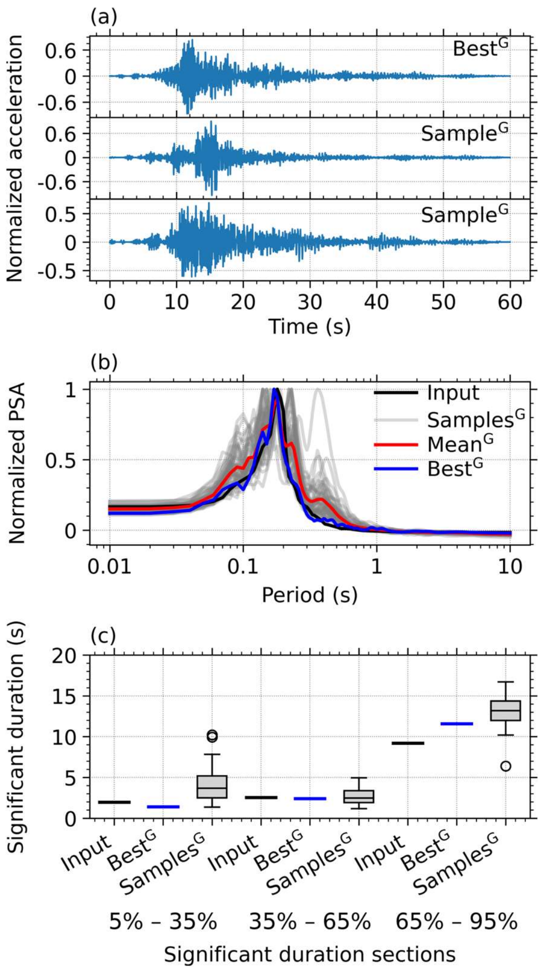

Fig. 1 Case 1: (a) Generated accelerograms, (b) PSA comparisons with the input PSA, and (c) significant duration comparisons.

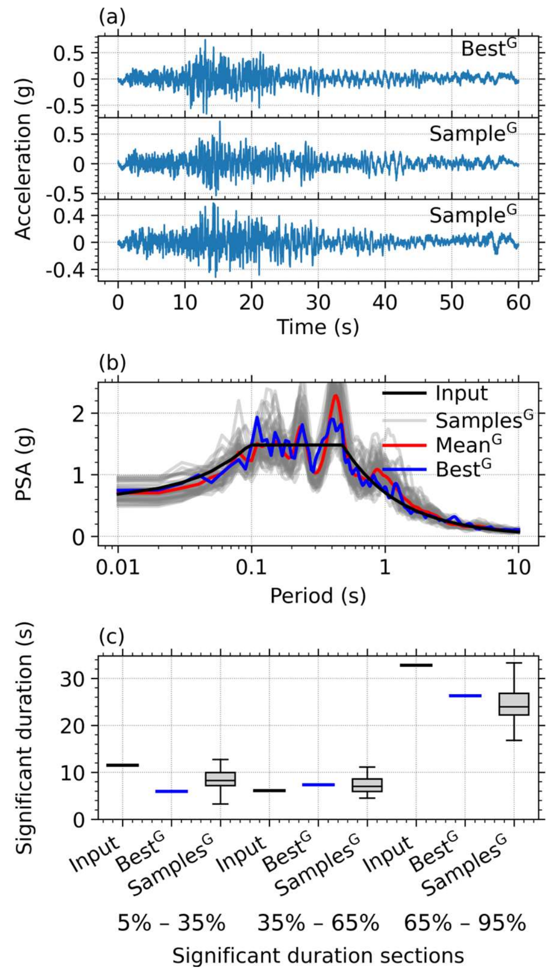

Fig. 2 Case 2: (a) Generated accelerograms, (b) PSA comparisons with the input design spectrum, and (c) significant duration comparisons.

inspection indicates that the generated samples generally align well with the conditional information. However, certain discrepancies occur, revealing limitations in the models when dealing with underrepresented values.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (RS-2024-00412801).

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