Synthesis and Selection of Seismic Design Input Ground Motions with Deep Learning

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Background

Seismic design principle has been changed from traditional force-based design to performance-based design. Besides the inner force, performance-based design takes more factors into consideration during an earthquake, which makes the result of seismic design more economical and reliable.

The nonlinear response of the structure is very complicated, and slight different condition can bring much uncertainties to the problem. Considering the general existence of uncertainty, performance-based design requires for dynamic time history analysis of structures, in which several (in most cases 3 to 7) proper input ground motions are needed according to some design code [1]. However, due to the limitation of seismic records, it's often difficult to get enough proper input ground motions. Therefore, some methods were brought up to generate large numbers of artificial ground motions based on stochastic model (especially, a method using continuous wavelet transform is raised in the thesis). In this thesis, deep learning tool was used to synthesis ground motions based on the large number of generated ground motions.

Objectives

The synthesis of ground motions can be regarded as a process of data compression, we hope to select or synthesis a ground motion to be representative of a set of possible ground motions. Conventionally, the characteristics of ground motions such as *Peak Ground Acceleration* were used to do the compression, some techniques such as information theory [2] and machine learning [3] have been used in this field. We hope to use more information from the ground motion set rather than only fix to only one or some characteristics.

Methodology

Based on stochastic model, we adopted Fourier Transform on seismic record. Because of resonance phenomenon, the nonlinear response of structure is very sensitive to ground motion which has frequency close to the natural frequency of the structure. By randomizing the phase of certain components, we can generate large numbers of ground motions and keep the frequency amplitude in the same time.

Autoencoder is a deep learning algorithm which are especially useful to deal with data compression. In this research, 20,000 randomization ground motions were generated from one seismic record, they were used as input ground motions to one structure model and do nonlinear dynamic analysis with OpenSEEs. 20,000 input ground motions and corresponding 20,000 response time history were generated as our data set, half of them are used as our training data, another half are test data. Response time history was input into an autoencoder to match an input ground motion. As the information of the input is been compressed among the layers in a neural network, in the latent layer, hopefully, we can find some abstract features which can be more efficient to describe the characteristics of ground motions. These features hopefully can help us to synthesis and modify the input ground motions.

Results

Our model can nicely rebuild an input ground motion from the response time history data.

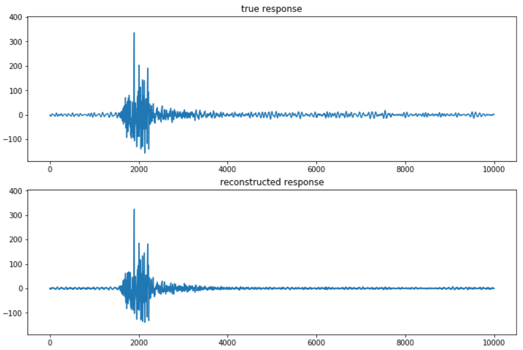

Figure 1: Compare of the real ground motion and reconstructed ground motion

The compression degree depends on the dimension of our deep learning model, in our case, input data is compressed to a 3-dimensional latent space, each dimension of which can be regarded as a feature of the response data.

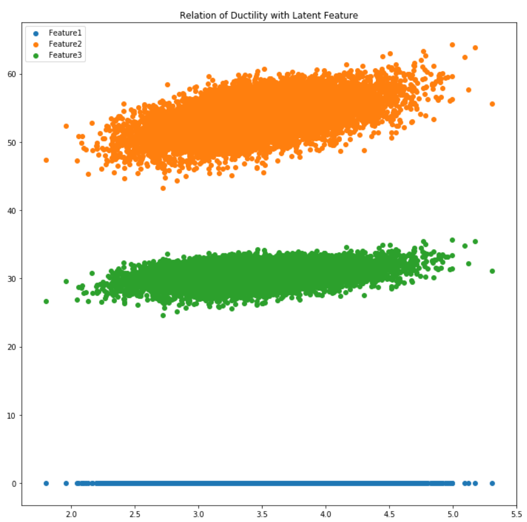

Figure 2: Three features of response time history in latent space

By identifying the abstract feature with, for example, the ductility of the structure, we can find one which is most related, then the feature can be manipulated and pass through the decoder model to generate an enhanced or weaken input ground motion which is also representative with the set of input ground motions.

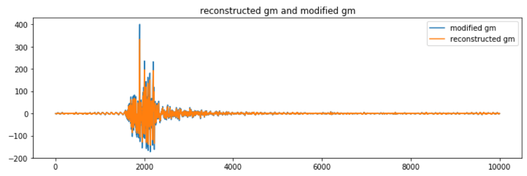

Figure 3: Compare of enhanced ground motion and reconstructed ground motion without being modified

Conclusion

Autoencoder and deep learning can be a very useful tool to synthesis large numbers of input ground motions. Rather than predetermining several characteristics of input ground motion, this method can take all the information of the set of ground motions into consideration. Also, it can help to generate an enhanced ground motion based on the training data.

Reference

1. Alimoradi, Arzhang and James L Beck (2014). "Machine-learning methods for earthquake ground motion analysis and simulation". In: Journal of Engineering Mechanics 141.4, p. 04014147.

2. Azarbakht, A and MG Ashtiany (2008). "The code-based selection of ground motion records for nonlinear time-history analysis". In: 14th World Conference on Earthquake Engineering, Beijing, China. Citeseer.

3. Miyamoto, Takashi and R Honda (2012). "Synthesis of design input motion reflecting the information of possible ground motions". In: Proceedings of 15th World Conference on Earthquake Engineering.