Input motion synthesis based on the time-frequency characteristics of the response of non-linear systems

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1. Introduction

To implement the achievement of the seismology in the context of engineering, it is essential to unite the concepts of the needs of engineering and the findings from seismological viewpoints. Advanced seismic design methods requires synthesis of input motions paying sufficient attention to the nonlinear response of structures.

2. Wave synthesis from TF characteristics of the nonlinear system response

Response spectra have been used to discuss the frequency characteristics of the ground motions. In recent days, as the importance of nonlinear response of the structure is recognized, time-frequency (TF) characteristics are also used. It would be possible to discuss the TF characteristics of the response of the non-linear system in the selection of design input motions. It enables us to see how the input motions affects the behavior of structures when it is damaged and starts behaving in the nonlinear manner.

One of the difficulties of using TF characteristics of the nonlinear response lies in the synthesis of the corresponding time series signal. Since nonlinear response does not preserve the information of input motion perfectly, it is impossible to obtain the input motion by inverse analysis. We use a searching algorithm as a wave synthesis tool based on the TF characteristics of nonlinear system response.

2.1 TF characteristics

TF characteristics of the nonlinear response are evaluated using the continuous wavelet transform of the time history of the response of a nonlinear single degree of freedom system. Bilinear model is used in this report, but other nonlinear models can be used.

We consider a complex wavelet function and it gives complex-valued wavelet transform. It is not suitable, however, for the practical purpose of specification of input ground motion for design. Therefore, we use the absolute value of the wavelet, discarding the “phase” values.

2.2 Wave synthesis scheme

The wavelet transform keeps the information of the transfer function. It is possible to obtain the input signal from the wavelet transform of the output signal by using the transfer function, as long as a linear system is considered. It does not hold rigorously when the system is nonlinear. In the proposed scheme, it is exploited that the transfer function of a linear system which is “equivalent” to the nonlinear system enables us to obtain an approximation of the input signal.

The wave synthesis is conducted in a step-wise searching procedure. Suppose the target TF characteristics is specified as mentioned above. We start the procedure with some candidate wave. (It can be a constant zero signal.) The approximation of the TF characteristics of an input is estimated using the transfer function of an equivalent linear system. Then we estimate the difference of the TF characteristics of the “approximated” and “candidate” waves. Several wavelet functions are generated randomly in the vicinity of the peak of the differential TF characteristics. The waves are added to the candidate wave to generate modified candidate waves and the one whose TF characteristics is the closest to the target is adopted as the updated candidate wave. The procedure is iterated until the TF characteristics of the candidate wave are sufficiently close to the target TF characteristics.

3. Applications

The proposed scheme is applied to the cases where several ground motion records obtained in the Kobe Earthquake are used. In spite of the simple algorithm, the generated waves exhibit good approximation of the TF characteristics of the nonlinear response of original waves. The obtained waves are not exactly identical time history of the original input motions, but they should be suitable for the design purposes.