



## An artificial earthquake generation using the phase differentiation

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### ABSTRACT

A simple and efficient method which utilizes the phase difference spectrum is suggested in this paper for an artificial earthquake generation, given a shape of envelop curve. The basic idea featured in this method is that the phase difference spectrum should be related with some characteristics of an strong earthquake. This paper shows that the distribution of phase difference using an envelop curve as a probability distribution is similar to a shape of an artificial earthquake.

### 1. INTRODUCTION

Owing to the randomness of the fault rupture process and the complexity of source, path and local site conditions, it is necessary to use simulated earthquake ground motions with real records to assess the seismic safety of structures<sup>[1]</sup> excited by an earthquake. The design spectrum for earthquake ground motion used in Korea is based on the earthquake of a foreign country since there have been no strong earthquake records in the Korean peninsula until now. However, this unproved current practice will lead to significant disaster when applied to safety related structure because the geologic site conditions in Korean peninsula is very different from those in a foreign country.

The objective of this paper is to present an efficient and simple method for artificial earthquake generation. In the method, earthquake ground motion is generated based on the relation between phase difference spectrum and envelop curve.

### 2. PHASE DIFFERENCE SPECTRUM

The phase difference is defined as the difference between two adjacent phase angles. It can be expressed as follows<sup>[5]</sup>:

$$\Delta\phi_k = \phi_{k+1} - \phi_k \quad (2)$$

in which,  $\phi_k$  ( $k=1,2,\dots,N/2-1$ ) is the series of phase angle. The phase difference spectrum is defined as the distribution of  $\Delta\phi_k$  in Eq. (2).

To derive the relationship between envelop curve of earthquake records and phase difference,

certain form of the probability density distribution (See Figure 1(a)) is used as one of an envelop curve in this study. The cumulative probability density distribution shown in Figure 1(b) can be obtained, and then probability variables can be obtained by the corresponding value of random number generated arbitrarily from 0 to 1. The phase difference is defined as the probability variables multiplied by  $-2\pi$ . Therefore, the phase difference spectrum can be plotted by the relationship between the density distribution and the phase difference (See Figure 1(c)). The distribution of the phase angle is also shown in Figure 1(d).

The phase angle can be determined as follows<sup>[5]</sup> :

$$\phi_{k+1} = \Delta\phi_k + \phi_k \tag{3}$$

It should be noted that while arbitrary form of the probability density distribution is used as one of an envelop curve for calculating the phase difference in this study, the form of an envelop curve is very similar to the one of the phase difference spectrum as shown in Figure 1(a) and 1(c). However, the distribution of the phase angle obtained by the phase difference is random, displaying no characteristic features<sup>[6]</sup>.

### 3. RELATION BETWEEN PHASE DIFFERENCE SPECTRUM AND ENVELOP CURVE

From the results of the previous review, it is observed that the distribution of the phase angle obtained by using the phase difference spectrum is always random. It is also shown that waveform converted from the phase angle by the inverse Fourier Transform is very similar to phase difference spectrum.

In order to examine the relationship between the phase difference spectrum and envelop curve, four different cases of the phase difference spectrum shown in Figure 2 are considered in this study. In these cases, Ohsaki response spectrum<sup>[5]</sup>, which is obtained by empirical formula, is used as amplitude information for inverse Fourier Transform.

The relationship between the phase difference spectrum and envelop curve is illustrated in Figure 2 for four different cases. It is shown in Figure 2(a) that the waveform is mainly concentrated on the central part of the horizontal axis as the phase difference distribution. Similarly, the waveform is concentrated on the early part(Figure 2(b)) and uniformly distributed(Figure 2(c)) according to the respective phase difference spectrum. The waveform shown in Figure 2(d) is the case for the phase difference distributed with an easy slope on the whole duration. From these figures, it can be asserted that there are certain similarities between the envelop curve and the phase difference spectrum regardless of the phase difference distribution. However, it is shown that there are always the random characteristics in these four cases of the phase spectrum.

For more detailed consideration, the Ohsaki envelop curve<sup>[4]</sup> shown in Figure 3(a) is examined in this study. The results of this problem obtained by using this method are shown in Figure 3(c). It is shown in Figure 3 that there is no difference between the envelop curve and the phase difference spectrum for this problem. The waveform is similar to the form of the envelop curve.

In order to examine the physical meaning of this relation between the phase difference spectrum and the envelop curve, Jennings's envelop is considered in Figure 4. Jennings's envelop curve<sup>[2]</sup> is dependent on the earthquake magnitude and the ground factor. As shown in Figure 4(c), the similarity between phase difference and envelop curve is also observed. In Figure 5, the results for the case of specific envelop curve having two large peaks are shown. Even when the case of the notorious envelop curve is examined as exemplified in Figure 5, the

phase difference spectrum is similar to the envelop curve. But, the waveform is not similar to the envelop curve. These similarities between the phase difference spectrum and the envelop curve of waveform are not able to be explained completely. These problems will be solved in the future work.

#### 4. CONCLUSIONS

Usually earthquake records are represented with various patterns of phase difference spectrum and waveform depending on the geologic site condition and earthquake parameters (peak acceleration, duration time, envelop curve, frequency content and etc.)<sup>[3]</sup>. Therefore a simulation method that can control the properties of the earthquake ground motion should be developed so that the method can incorporate the newly known characteristics of earthquake ground motion.

An efficient and simple method for artificial earthquake generation is suggested in this study. The main idea used in this method is that the phase difference has some characteristics of an earthquake. It is shown that the distribution of the phase difference using an envelop curve as a probability distribution is similar to a shape of an artificial earthquake. It is expected that this method suggested in this study will be a efficient method for artificial earthquake generation.

#### References

1. Housner, G.W., P.C. Jennings 1964. Generation of artificial earthquakes. *Journal of the Engineering Mechanics Division, ASCE* 90: 113-149.
2. Jennings, P.C., G.W. Housner & N.C. Tsai 1968. *Simulated earthquake motions*. Earthquake Engineering Research Laboratory, California Institute of Technology.
3. Katukura, H., T. Watanabe & M. Izumi 1978. A study on the phase properties of seismic waves. *Proc. 5th Japan Earthquake Engineering Symposium*: 209-216.
4. Ohsaki, Y., J. Kanda & R. Iwasaki & T. Masao & Y. Kitada & K. Sakata 1984. Improved methods for generation of simulated earthquake ground motions. *Proc. 8th WCEE*.
5. Ohsaki, Y. 1994. *An introduction to spectrum interpretation of earthquake ground motion*. Lokusima Press : Japan.
6. Shinozuka, M., Y. Sato 1967. Simulation of nonstationary random process. *Journal of the Engineering Mechanics Division, ASCE* 93: 11-40.

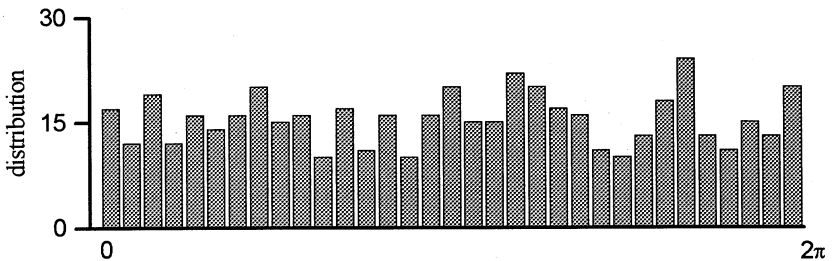
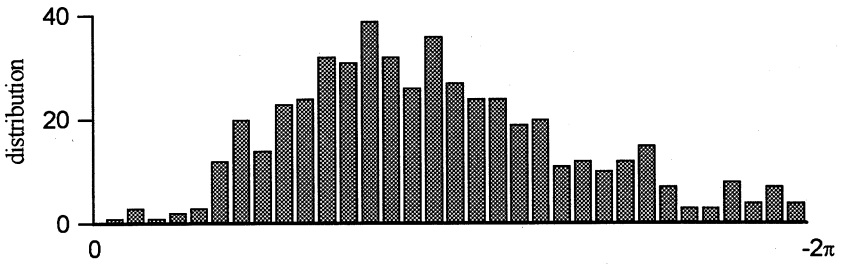
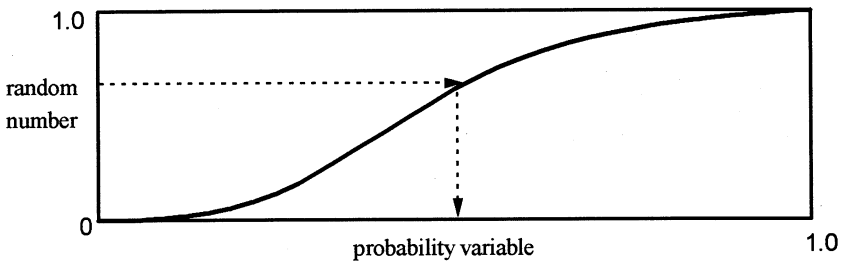
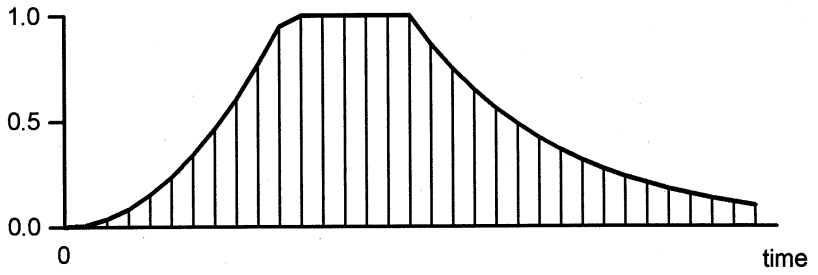
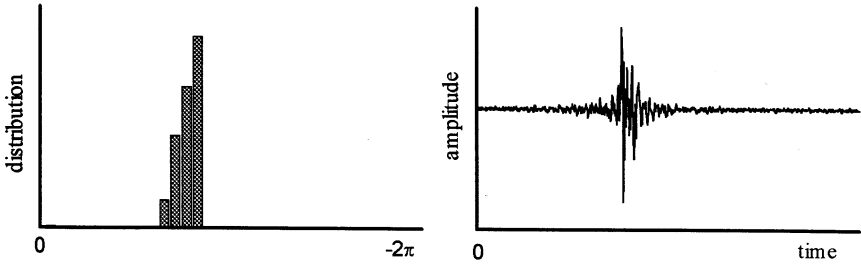
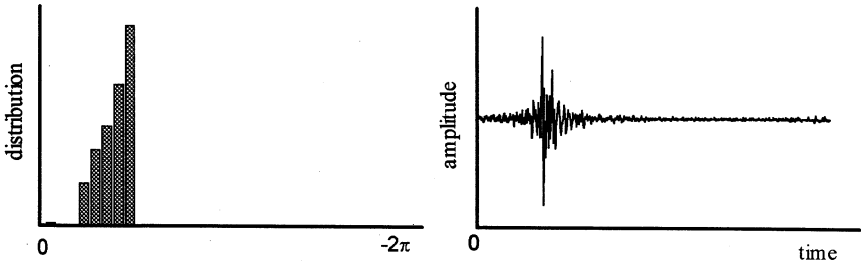


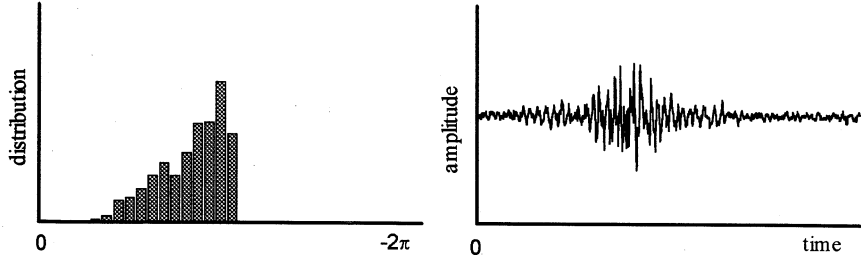
Fig 1. Envelop curve and phase difference spectrum



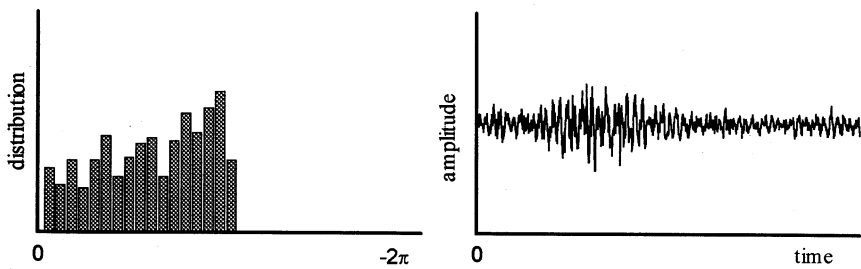
(a) Sample phase difference(rad) 1 and waveform



(b) Sample phase difference(rad) 2 and waveform

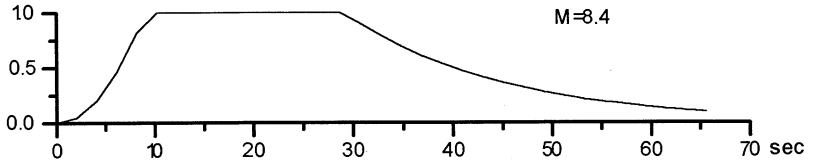
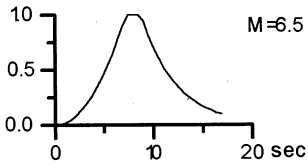


(c) Sample phase difference(rad) 3 and waveform

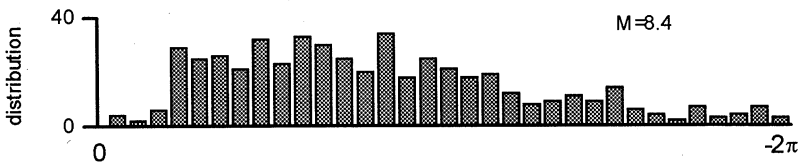
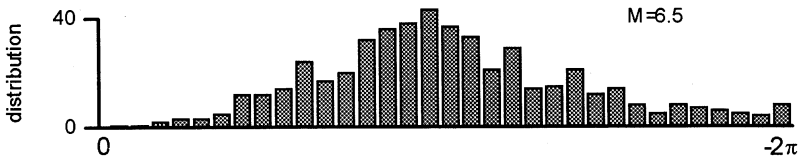


(d) Sample phase difference(rad) 4 and waveform

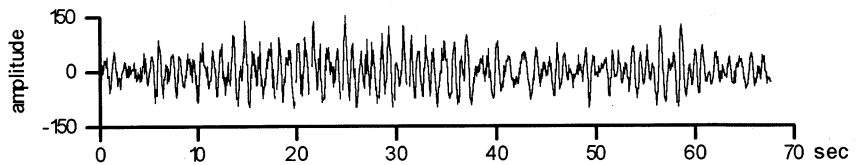
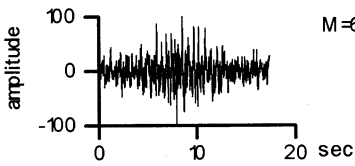
Figure 2. The relation between phase difference spectrum and wave form



(a) Ohsaki's envelope curves

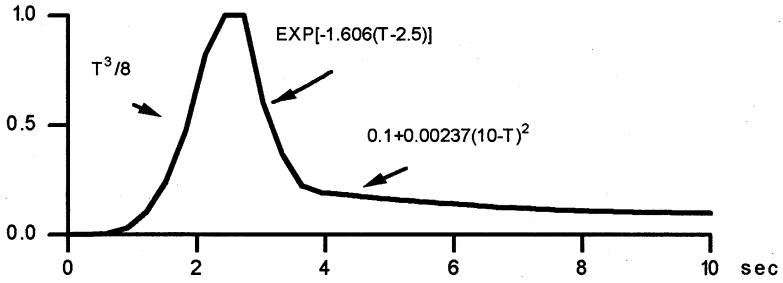


(b) Phase difference spectrum

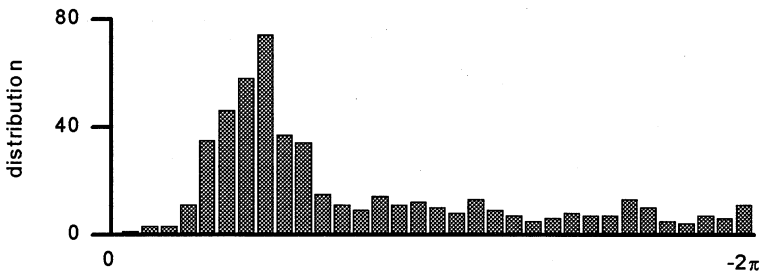


(c) Acceleration time history

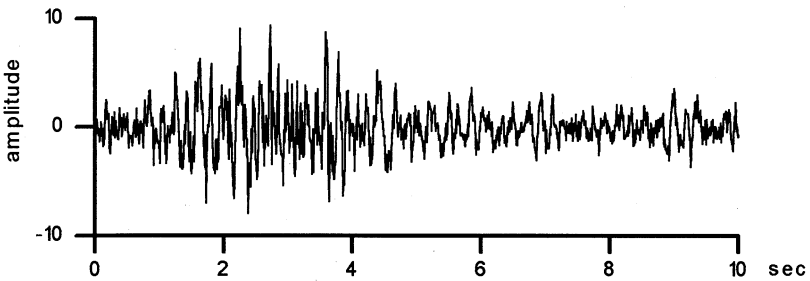
Figure 2. Ohsaki envelop curve according to the earthquake magnitude



(a) Jennings' envelope curve

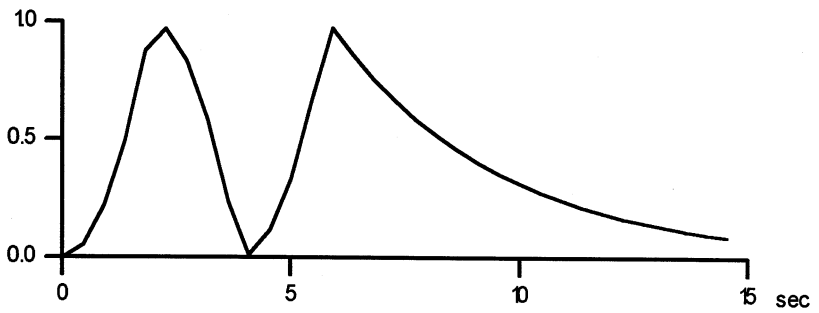


(b) P hase difference spectrum

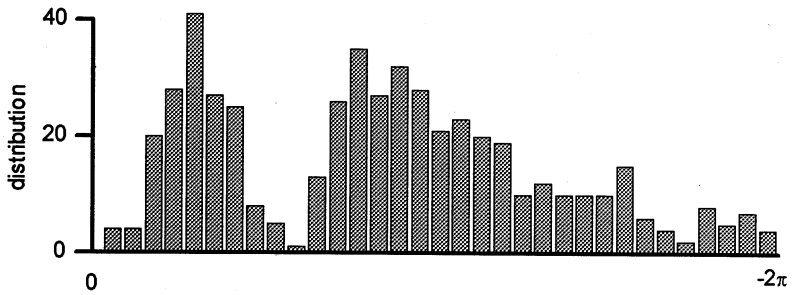


(c) A cceleration time history

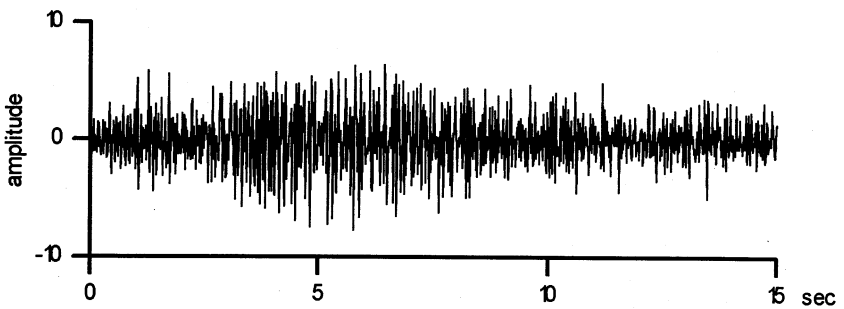
Figure 4. Jennings' envelop curve and comparison of phase difference spectrum with acceleration time history



(a) Arbitrary envelope curve



(b) Phase difference spectrum



(c) Acceleration time history

Figure 5. Arbitrary envelop curve and comparison of phase difference spectrum with acceleration time history