Simulations of Non-stationary Frequency and Its Importance to Seismic Assessment of Structures

Tongji University M. of CCES ○Junjie Wang
Tongji University M. of JSCE Limin Sun
Tongji University M. of CCES Lichu Fan

Introduction

Currently, the most commonly used random model to generate artificial seismic wave is written as:

$$a(t) = f(t) \cdot x(t) \tag{1}$$

where $f(t)$ is a deterministic absolute amplitude envelope function with a maximum value of 1, and $x(t)$ is a stationary random process. Eq.1 is traditionally called a uniform modulating random process, which describes a class of random processes with non-stationary intensity but time-invariant(constant) frequency content. But measured ground motions are time series with both intensity and frequency non-stationarities. In this paper, a fully non-stationary ground motion model is employed to verify the importance of non-stationary frequency characteristic of seismic ground motion to seismic response and seismic capacity assessment of structures.

Fully Non-stationary Seismic Ground Motion

As mentioned earlier, the currently used earthquake ground-motion model in Eq.1 failed to characterize the time-varying nature of frequencies in seismic actions. To overcome this shortcoming, the so-called evolutionary random process model was proposed (Nigam, 1983), that is,

$$a(t) = \int_{-\infty}^{\infty} A(t,w)e^{iwt}dF(w) \tag{2}$$

where $i = \sqrt{-1}$, and $A(t, w)$ is a deterministic frequency-time modulating function. It represents an absolute amplitude envelope of a seismic process. $dF(w)$ is a zero-mean, mutually independent, orthogonal increment process. To determine the function of $A(t,\omega)$, a joint time-frequency analysis technique of time signals, called chirplet-based signal approximation, is imployed in this paper. For a given signal $s(t)$, the adaptive spectrogram, i.e.,

$$AS(t,w) \approx \sum_{k=0}^{K} \frac{2p}{a_k}(A_k)^2 e^{-a_k(t-t_k)^2-[w-w_k-b_k(t-t_k)]^2/a_k} \tag{3}$$

For the purpose of this paper, the adaptive spectrograms of the corresponding recorded seismic signals are normalized as the follows:

$$A(t,w_k) = AS(t,w_k)/\underset{\text{for all } t}{Max}(AS(t,w_k)), \quad k = 1,2,\cdots \tag{4}$$

After obtaining $A(t,w)$, we apply Eq.1 and 2 to generate the artificial seismic waves using the trogonometric method. While Figures 2a represents the artificial seismic waves based on Eq.1, 2b is generated by Eq.2.

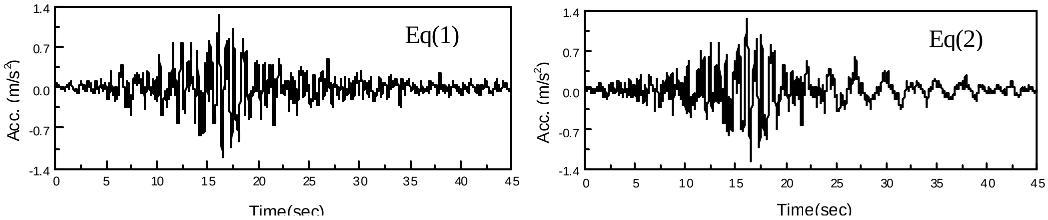

Figure1. The Artificial Seismic Waves

Keywords: Seismic Ground Motion, Non-stationary Frequency, Simulation
Address: State Key Laboratory for Disaster Reduction in Civil Engineering, Siping Rd. 1239, Shanghai 200092, China
Tel: (+86) 21 6598 0952, Fax: (+86) 21 6598 4882, Mail: lmsun@pop07.odn.ne.jp

Seismic Response of Structure

To verify the importance of the non-stationary frequency to the seismic response of structure, a 3-bay and 10-story frame is analyzed in this paper. The peak values of the artificial waves is adjusted to 0.5g. The results of structural responses are illustrated in Figure 2 and 3.

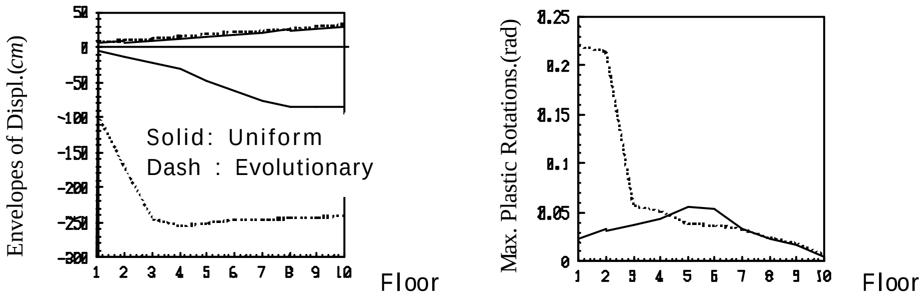

Figure 2 Displacements and Plastic Rotations at Joints of Columns and Beams

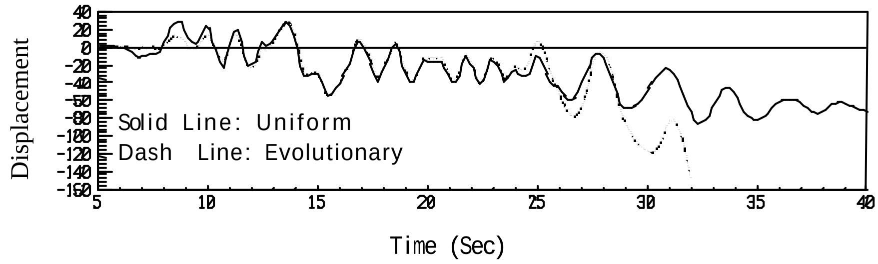

Figure 2 Displacement Response Histories at the Top Floor(*cm*)

It can be observed from Figure 2 and 3 that the non-stationary frequency of the seismic ground motion increases significantly the response displacements at the floors and the plastic rotations at the ends of the beams. The increment may reach more than 50%-100%. The results show that the feature of non-stationary frequency of seismic ground motion is of practical importance to the reasonable prediction of seismic responses and the seismic capacity assessment of structures, particularly for the collapse assessment of structures under seismic action. The results presented in this paper strongly suggest a need of modification of current method generating artificial seismic waves, i.e., equation (1) should be replaced by more reasonable random process model, for example, equation (2).

Conclusions

In this paper, the importance of the non-stationary frequency of seismic ground motion to structural response is studied. We have reached the following conclusions: (1) Using non-stationary frequency information, we can substantially improve the artificial seismic waves, in terms of preserving the non-stationary intensity and frequency content, which are presented in recorded accelerograms; (2) The non-stationary frequency characteristic of seismic ground motion may have important effect on the nonlinear response of structures, including displacement responses and internal force responses. The results show that to reach a reasonable assessment of seismic capacity of structures if the artificial seismic waves are employed, the non-stationary frequency characteristic should be included in the generation of artificial seismic waves with the non-stationary intensity of the seismic ground motion.

REFERENCES

1. Conte, J.P. and Peng, B.F.(1997), 'Fully Nonstationary Analytical Earthquake Ground-Motion Model.', ***Journal of Engineering Mechanics***, **123(1)**, American Society of Civil Engineers, 15-24.

3. Kannan, A.E., Powell, G.H., General purpose computer program for dynamic analysis of inelastic plane structures, UCB/EERC, 73/06.

3. Nigam, N.C.(1983), *Introduction to Random Vibrations*, Cambridge, Mass:MIT Press, 1983

2