Generation of Design Basis Earthquake Accelerograms

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SUMMARY:
This paper proposes a parametric analysis of the record data sets of the SAC Steel Project for generation of design basis earthquake records. The record parameters define design basis earthquake characteristics such as power spectral density and envelope function. A set of design basis earthquake accelerograms is generated based on the record parameters. In order to assess the reliability and efficiency of the proposed method, the statistical response spectra obtained from the generated accelerograms have been compared with those from the actual records. The obtained results showed that there is a good compatibility between the response spectra of the generated and actual records.

Keywords: design basis earthquake; power spectral density; envelope function; response spectra

1. INTRODUCTION

The generation of earthquake ground motions is important for the design of engineering structures under seismic excitation. For generation of earthquake records, stochastic approaches have been applied in nonstationary model in the literatures. According to nonstationary nature of earthquake records, conventional methods applying stationary concept might mislead the consequent use of ground motion data addressing different problems in engineering. Nonstationary approaches to generate artificial accelerograms were later introduced and applied to tackle shortcomings in the stationary methods (Giaralisa and Spanos, 2009; Zafarani et al., 2009; Cacciola, 2010). Some studies were established to simulate accelerogram using generalized well known Kanai-Tajimi model which includes nonstationary nature of frequency and amplitude (Fan and Ahmadi, 1990; Refooei et al., 2001). Lastly, Ghodrati Amiri and Bagheri (2009) presented a method based on nonstationary Kanai-Tajimi model and wavelet analysis for simulation of earthquake records. Furthermore, Iyama and Kuwamura (1999), Mukherjee and Gapta (2002), Suarez and Montejo (2005), Hancock et al. (2006), and Ghodrati Amiri et al. (2007) developed the wavelet-based method for the generation of artificial earthquake ground motions.

The sets of the strong ground motions for the SAC steel project were developed to represent uniform hazard criteria for given geographical regions based on rigorous theoretical seismology and numerical simulation procedures and contain 20 representative accelerograms for a specified region and hazard level (Somerville et al., 1997). A far larger number of representative accelerograms are required for structural analysis where higher resolution of the fragility of the system is required. The significance of this unique data set has motivated a careful examination of the statistical variability in the ground motion model parameters describing the individual ground motions.

In this paper, a parametrically model using the SAC Steel Project suites of strong ground motions to generate design basis earthquake records is presented. Parameter values that describe the power spectrum of the high-frequency and the low-frequency contents and the time modulating envelope function are determined for each record. A systematic fitting of parameterized envelopes to the individual instantaneous ground motion amplitudes, and of parameterized power spectral density functions to power spectra result for ground motion parameters representative of particular seismic hazard levels for specific geographical regions have been devised. Finally, using the obtained result for parameters from the SAC ground motion data sets, a set of design basis earthquake accelerograms is generated and statistically analyzed.

2. PROPOSED METHODOLOGY

The power spectrum density function of earthquake record can be defined as:

$$S(\omega) = S_0 \left|H_g(\omega)\right|^2 \left|H_h(\omega)\right|^2 \tag{2.1}$$

where $H_g(\omega)$ and $H_h(\omega)$ are high and low frequency response functions, respectively; S_0 is the constant power spectral intensity.

High frequency response function can be express as:

$$\left|H_g(\omega)\right|^2 = \frac{\omega_g{}^4 + (2\xi_g \omega_g \omega)^2}{(\omega_g{}^2 - \omega^2)^2 + (2\xi_g^j \omega_g \omega)^2} \tag{2.2}$$

where ξ_g and ω_g are site dominant damping coefficient and ground frequency for the high frequency content, respectively.

Also, low frequency response function can be written as:

$$\left|H_h(\omega)\right|^2 = \frac{\omega^4}{(\omega_h{}^2 - \omega^2)^2 + (2\xi_h \omega_h \omega)^2} \tag{2.3}$$

where ξ_h and ω_h are site dominant damping coefficient and frequency for the low frequency content, respectively.

In order to determine the constants of S_0, ξ_g, ξ_h, ω_g, and ω_h for a design basis earthquake record, the power spectrum density of the design basis earthquake record is obtained based on:

$$S(\omega) = \frac{\left|F(\omega)\right|^2}{\pi T_D} \tag{2.4}$$

where $F(\omega)$ is the finite Fourier transform of the design basis earthquake record; and T_D is the duration of the design basis earthquake record. Then, the constants determine based on fit the power spectrum density to Eqn. 2.1. The power spectrum density function is shown in Fig. 2.1.

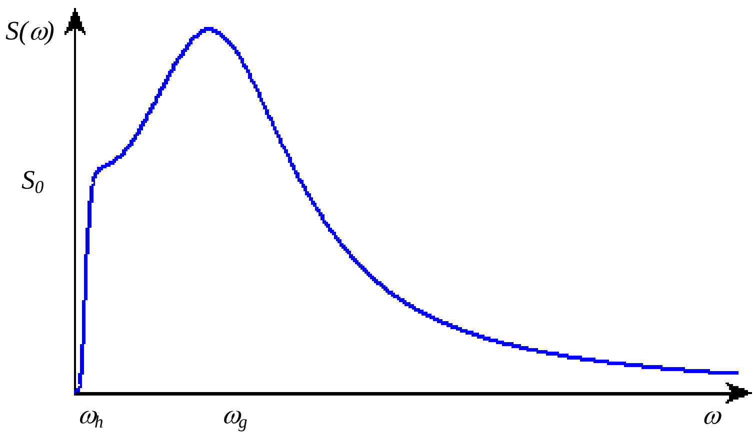

Figure 2.1. The power spectrum density function

Also, the amplitude envelope function can be defined as:

$$\begin{aligned} a(t) &= \left(\frac{t}{t_1}\right)^{\alpha} && for \quad 0 \le t \le t_1 \\ a(t) &= 1 && for \quad t_1 \le t \le t_2 \\ a(t) &= \exp\left(-\frac{t-t_2}{\beta}\right) && for \quad t_2 \le t \le T_D \end{aligned} \tag{2.5}$$

where t_1 is the time the earthquake takes to reach its peak acceleration; t_2 is the time the acceleration is at the plateau peak region; α is power of function and β is an exponential decay time constant.

Next, the first filtered response can be determined by:

$$\ddot{x}(t) + 2\xi_g \omega_g \dot{x}(t) + \omega_g^2 x(t) = n(t) \tag{2.6}$$

$$\ddot{x}_1(t) = -2\xi_g \omega_g \dot{x}(t) - \omega_g^2 x(t) \tag{2.7}$$

where *n(t)* is a stationary Gaussian white noise process; x_1 is first filtered responses. Then, the second filtered response can be written as:

$$\ddot{x}_2(t) + 2\xi_f \omega_f \dot{x}_2(t) + \omega_f^2 x_2(t) = \ddot{x}_1(t) \tag{2.8}$$

Lastly, the generated design basis earthquake accelerogram can be obtained as:

$$\ddot{x}_g(t) = \ddot{x}_2(t) a(t) \tag{2.9}$$

3. PARAMETERS AND EARTHQUAKE RECORDS RESULTS

The proposed method for generation of design basis earthquake record is applied to the generation of earthquake records for a specific hazard level based on the data sets of the SAC Steel Project. In the SAC Steel Project, the ground motion data sets developed for a specific hazard level and a specific geographic region. The hazard levels are classified in terms of exceedance probabilities in a particular time period. The design basis earthquake corresponds to a 10% probability of exceedance in fifty years. Each data set is a sample of ten bi-axial ground acceleration records (Somerville et al., 1997). In

this study, two geographic regions are considered namely Seattle and Los Angeles for the generation of earthquake records.
The parameter values ware obtained based on the presented method for the estimation of the parameters for the uniform hazard probabilities of exceedance of 10% in fifty years for two regions. Tables 3.1 and 3.2 indicate the means and standard deviation of these statistical parameters for Los Angeles and Seattle.

Tabal 3.1. The obtained parameters results for Los Angeles

	S_0(cm^2/sec^3)	ξ_g	ω_g(rad/sec)	ξ_h	ω_h(rad/sec)	t_1(sec)	t_2(sec)	α	β
Mean	263.4	1.60	11.74	0.79	0.43	4.78	8.96	2.60	0.13
Std. dev.	362.71	1.06	7.98	0.07	0.73	4.12	5.24	0.50	0.05

Tabal 3.2. The obtained parameters results for Seattle

	S_0(cm^2/sec^3)	ξ_g	ω_g(rad/sec)	ξ_h	ω_h(rad/sec)	t_1(sec)	t_2(sec)	α	β
Mean	117.52	1.39	13.38	2.37	0.79	7.12	20.06	1.50	0.08
Std. dev.	51.14	0.85	8.04	0.59	0.19	5.88	16.62	0.69	0.02

Based on the proposed technique for the generation of design basis earthquake records a set of fifty synthetic accelerograms was generated and statistically studied for any hazard level and region. Figure 3.1 shows an ensemble of generated records for the uniform hazard probabilities of exceedance of 10% in fifty years for Los Angeles. In addition, the generated records for design basis earthquakes for Seattle are indicated in Fig. 3.2.

Statistical response spectra of the generated design basis earthquake accelerograms have also been compared with those of the actual accelerograms. The mean values of the pseudo-acceleration response spectra for the set of fifty generated design basis earthquake accelerograms with those for the actual records are compared in Figs. 3.3 and 3.4. It can be concluded that the response spectra of the generated design basis earthquake accelerograms are close to the original record accelerograms in the most of the periods.

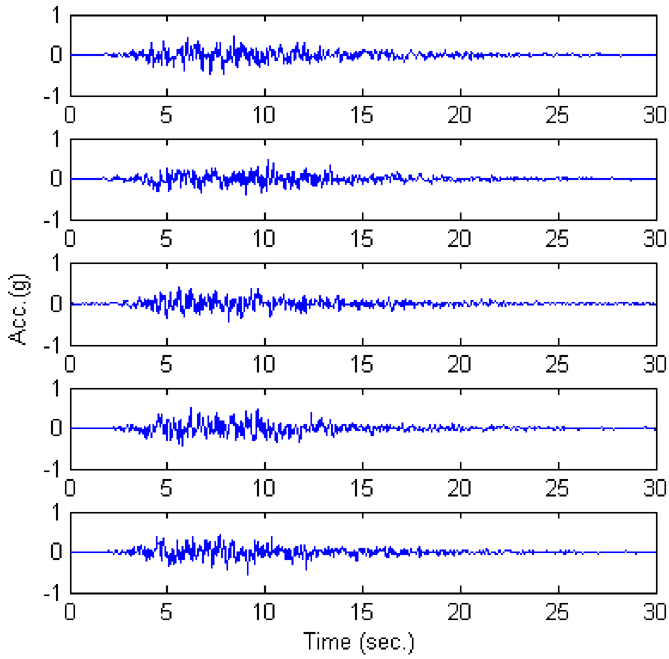

Figure 3.1. An ensemble of generated earthquake accelorograms for Los Angeles

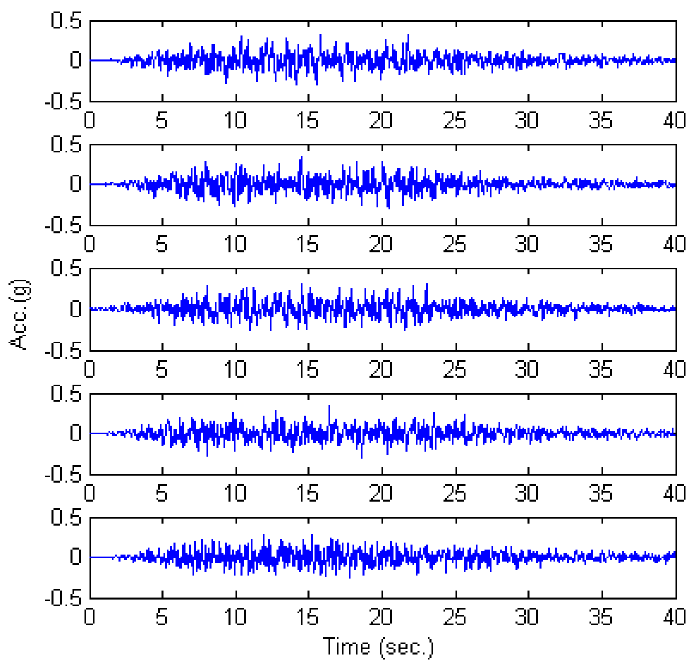

Figure 3.2. An ensemble of generated earthquake accelorograms for Seattle

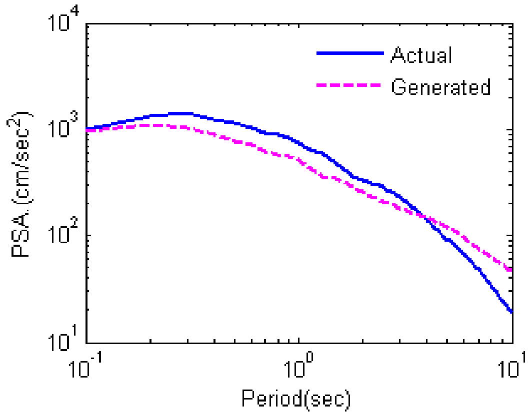

Figure 3.3. Comparison between the mean value of pseudo-acceleration response spectra of actual and generated records for Los Angeles

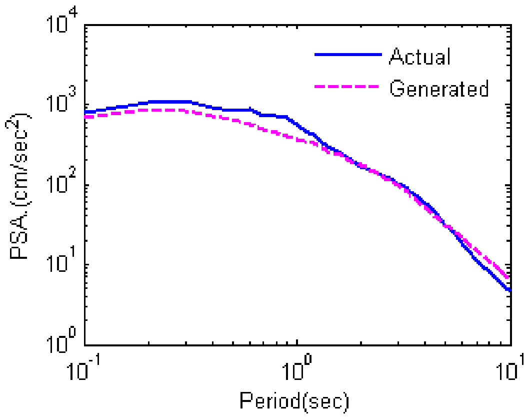

Figure 3.4. Comparison between the mean value of pseudo-acceleration response spectra of actual and generated records for Seattle

4. CONCLUSIONS

In this paper, the parameters of design basis earthquake ground motions such as the power spectra of the high-frequency and the low-frequency contents and the time modulating envelope function were determined. In addition, this study presented a method for generating design basis ground motions.

Based on the SAC ground motion data sets, a set of synthetic earthquake accelerograms generated and statistically analyzed. It is shown that the response spectra obtained from the generated design basis earthquake records are similar to that obtained from the original earthquake accelerograms in the most of the periods. Thus, the suggested methodology can be applied in the generation of design basis earthquake accelerograms.

REFERENCES

Cacciola, P. (2010). A stochastic approach for generating spectrum compatible fully nonstationary earthquakes. *Computers & Structures*. **88**,889-901.

Fan, F.G., and Ahmadi, G. (1990). Nonstationary Kanai-Tajimi models for El Centro 1940 and Mexico City 1985 earthquake. *Probabilistic Engineering Mechanics*. **5**,171-181.

Hancock, J., Waston-Lamprey, J., Abrahamson, N.A., Bommer, J.J., Markatis, A., Macoy, E., and Mendis, R. (2006). An improved method of matching response spectra of recorded earthquake ground motion using wavelets. *Journal* of *Earthquake Engineering*. **10:1**,67-89.

Giaralisa, A., and Spanos, P.D. (2009). Wavelet-based response spectrum compatible synthesis of accelerograms-Eurocode application (EC8). *Soil Dynamics and Earthquake Engineering*. **29**,219-235.

Ghodrati Amiri, G., and Bagheri, A. (2009). Simulation of earthquake records using combination of wavelet analysis and non-stationary Kanai-Tajimi model. *Structural Engineering & Mechanics*. **33:2**,179-191.

Ghodrati Amiri, G., Bagheri, A., and Fadavi, M. (2007). New method for generation of artificial ground motion by a nonstationary Kanai-Tajimi model and wavelet transform. *Structural Engineering & Mechanics*. **26:6**,709 -723.

Iyama, J., and Kuwamura, H. (1999). Application of wavelets to analysis and simulation of earthquake motions. *Earthquake Engineering & Structural Dynamics*. **28**,255-272.

Refooei, F.R., Mobarake, A., and Ahmadi, G. (2001). Generation of artificial earthquake records with a nonstationary Kanai-Tajimi model. *Engineering Structures*. **23**,827-837.

Mukherjee, S., and Gupta, K. (2002). Wavelet-based generation of spectrum-compatible time-histories. *Earthquake Engineering & Structural Dynamics*. **22**,799-804.

Somerville, P., Smith, N., Punyamurthula, S., and Sun, J. (1997). Development of ground motion time histories for phase 2 of the FEMA/SAC steel project (report no. sac/bd-97/04). FEMA/SAC Steel Project.

Suarez, L.E., and Montejo, L.A. (2005). Generation of artificial earthquake via the wavelet transform. *International Journal of Solids and Structures*. **42**,5905-5919.

Zafarani, H., Noorzad, A., Ansari, A., and Bargi, K. (2009). Stochastic modeling of Iranian earthquakes and estimation of ground motion for future earthquakes in Greater Tehran. *Soil Dynamics and Earthquake Engineering*. **29**,722-741.