TIME VARIATION OF GROUND MOTION FREQUENCY CONTENT: CHARACTERIZATION AND RELEVANCE

by

G. Rodolfo Saragoni[I] and Gary C. Hart[II]

SYNOPSIS

The time variation of amplitude and frequency content for the radial, tangential and vertical ground motion recorded at five southern California sites during the February 9, 1971, San Fernando earthquake is characterized. The importance of this variation upon the response of a stiffness degrading system is demonstrated using computer generated artificial earthquakes.

INTRODUCTION

The earthquake accelerograms recorded during the February 9, 1971, San Fernando earthquake showed a very clear variation in predominant frequency content with elapsed time. Herein, we use a nonstationary stochastic process to characterize the time variation in amplitude and frequency content which existed in the radial, tranverse and vertical directions at five southern California sites. This nonstationary stochastic process model is one for which an artificial earthquake simulation procedure has been demonstrated.(1)

The engineering importance of the ground motion's time varying frequency content is demonstrated using an example. Two ensembles of artificial earthquake accelerograms were generated - one ensemble having a time variation of frequency content and the other one having a time invariant frequency content. The sixteen sample functions of each ensemble were applied successively to a single degree of freedom stiffness degrading oscillator. Maximum structural response statistics were calculated and compared.

NONSTATIONARY STOCHASTIC MODEL

The ground motion experienced during an earthquake is assumed to be a segmented nonstationary stochastic process. Mathematically we write this stochastic process

$$a(t) = \psi(t) \sum_{j=1}^{3} \Lambda_j(t)\, n_j(t) \qquad (1)$$

where
$a(t)$ = ground acceleration
$\psi(t)$ = time modulating envelop function
$n_j(t)$ = stationary stochastic process
$\Lambda_j(t) = H(t-t_{j-1}) - H(t-t_j)$
$H(t)$ = Heaviside unit step function

The above equation assumes that the ground motion is modeled as three contiguous regions: Build-Up($t_0 \le t \le t_1$); Strong Motion ($t_1 \le t \le t_2$) and Die Down ($t_2 \le t \le t_3$). The following two sections establish for each record the time modulating envelop function and power spectral density function for each stationary stochastic process.

I. Former Graduate Student, Univ. of California, Los Angeles; now Professor, Departamento de Obras Civiles, Universidad de Chile.

II Assistant Professor, **University of California,** Los Angeles

ENVELOP FUNCTION

The envelop function of the process defined in Eq.(1) can be shown to be equal to the square root of the ground motions mean square acceleration. Herein we postulate that the mean square acceleration is of the mathematical form

$$E\{a^2(t)\} = \beta t^\gamma e^{-\alpha t} \tag{2}$$

and then the expected energy function, defined,

$$E\{W(t)\} = \int_0^t E\{a^2(\tau)\} d\tau \tag{3}$$

can be directly expressed in terms of α, β, and γ. Note that when the upper limit of the integral in Eq.(3) is infinity the resulting quantity is the total energy and is directly related to the Arias and Housner intensities.

For each ground motion noted in Table 1 the expected energy function, Eq.(3), was evaluated as a function of time. A least squares fit was then used to establish corresponding best fit values for α, β, and γ. These values are given in Table 1. Herein, β, is treated as an amplitude scale parameter with α and γ being the acceleration envelop shape parameters.

FREQUENCY VARIATION WITH TIME

Each earthquake acceleration verses time history was divided into a build-up, a strong motion and a die down region as noted in Table 1. The stochastic process in each time region is assumed to be stationary with a unimodal power spectral density function of the form

$$S(\omega) = S_o|\omega|^P e^{-|\omega|Q} \tag{4}$$

The parameters P and Q are determined for each time region using intensity functions of zero crossings and maxima. We select S_o such that when we integrate the function in Eq.(4) over the entire frequency domain we obtain unity. Table 1 gives the values of these parameters for the selected accelerograms. Reference 1 shows plots of the power spectral densities. The plots indicate an acceptable description of frequency variation with time.

STRUCTURAL RESPONSE

The segmented nonstationary stochastic process used to characterize earthquake ground motions can also be used to simulate artificial earthquake records. Using the procedure described in Reference 1 we generated two ensembles of artificial earthquake accelerograms. The first ensemble consisted of 16 sample functions whose characterization parameters for α, β, and γ are the same as for the 8244 Orion radial motion, see Table 1, and whose frequency content is time invariant. That is, we used only one time region and selected P and Q to be the same as that for the 8244 Orion radial strong motion time region-i.e., P = 0.23 and Q = 0.075. This ensemble is hereafter call the Stationary Frequency ensemble. A second ensemble of 16 artificial earthquakes, called Nonstationary Frequency, were generated using three time regions and the same characterization parameters as were obtained in the analysis of the ground motion in the radial direction at 8244 Orion, see Table 1.

The response of a single degree of freedom stiffness degrading oscillator was calculated for each sample function in both artificial earthquake ensembles. Figure 1 shows a comparison of the maximum responses experienced for each ensemble. In effect what seems to happen is the effective period elongates due to yielding as time evolves and hence this structure with a longer effective period tunes in with the longer ground motion periods which excite the system later in the response time domain.

REFERENCE

1. Saragoni, G. R. and Hart, Gary C., "Nonstationary Analysis and Simulation of Earthquake Ground Motions," UCLA Tech Report, ENGR-7238, June, 1972.

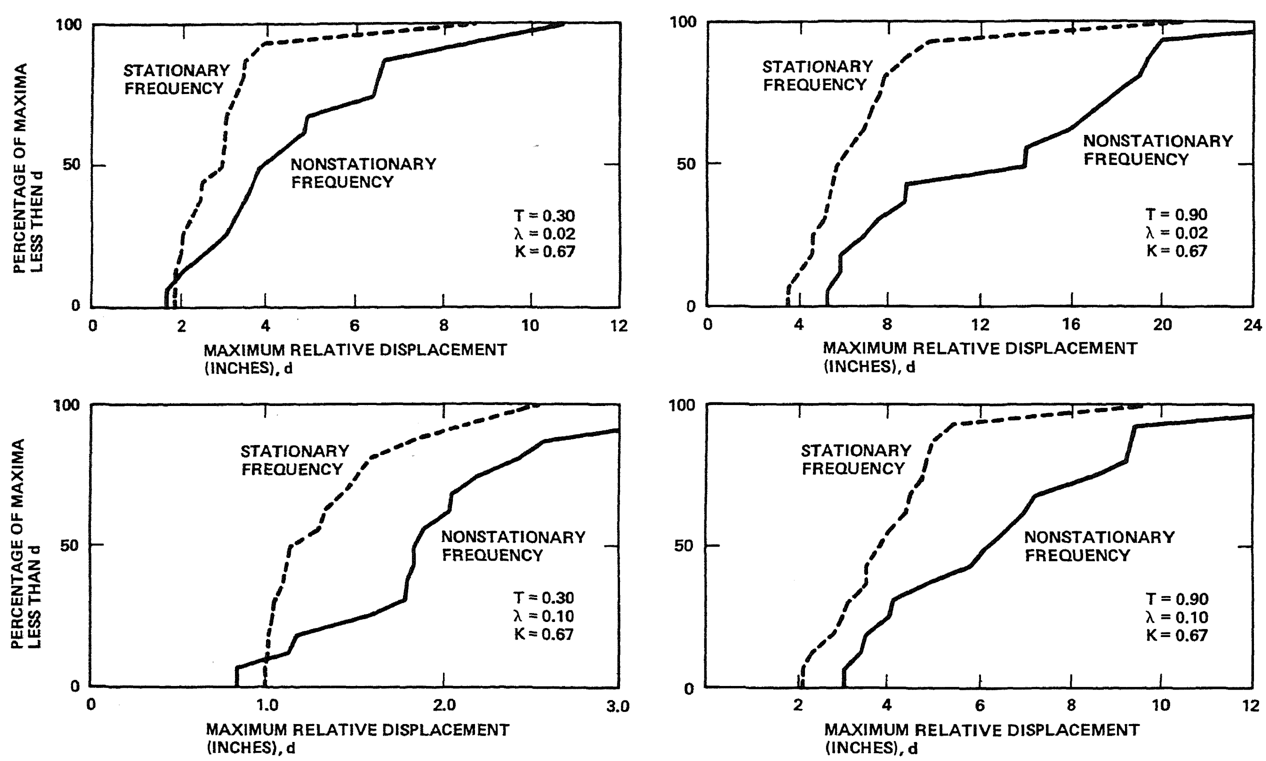

Figure 1. Response of Stiffness Degrading System

Table 1
NONSTATIONARY GROUND MOTION CHARACTERIZATION

STATION	DIST. (km)	COMPONENT	RECORD LENGTH (sec)	TOTAL ENERGY (10^{-2}g-sec)	α (sec)$^{-1}$	β (10^{-2}g-sec)	γ	TIME REGION	P	Q	TIME REGION	P	Q	TIME REGION	P	Q
Pacoima Dam	8	Radial	30.0	70.38	1.042	.227	5.69	0-7.8	.769	.053	7.8-17.4	.39	.053	17.4-30.0	.035	.056
		Tangential	30.0	42.31	1.176	.026	7.09	0-30.0	.890	.056	—	—	—	—	—	—
		Vertical	30.0	28.75	0.970	.403	4.58	0-9.3	3.25	.093	9.3-19.2	2.29	.079	19.2-30.0	1.59	.070
8244 Orion	21	Radial	30.0	7.77	0.454	.014	3.65	0-4.8	1.90	.098	4.8-12.2	.23	.075	12.2-30.0	.187	.305
		Tangential	30.0	4.79	0.436	.006	3.76	0-4.6	1.60	.090	4.6-11.9	.12	.071	11.9-30.0	.41	.27
		Vertical	30.0	4.40	0.206	.166	1.06	0-6.1	1.34	.088	6.1-14.8	.30	.077	14.8-30.0	1.76	.91
15250 Ventura	29	Radial	27.5	5.27	0.401	.009	3.44	0-4.9	2.41	.103	4.9-12.2	.80	.090	12.2-27.5	1.53	.41
		Tangential	27.5	3.18	0.326	.006	3.04	0-6.9	2.80	.143	6.9-15.7	1.76	.136	15.7-27.5	.93	.14
		Vertical	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Hollywood Storage Parking Lot	35	Radial	30.0	1.61	0.369	.101	1.49	0-6.6	2.04	.114	6.6-15.6	.79	.100	15.6-30.0	1.65	.21
		Tangential	30.0	2.39	0.350	.221	1.18	0-6.3	0.09	.073	6.3-15.1	.06	.196	15.1-30.0	.94	.29
		Vertical	30.0	0.43	0.228	.053	0.49	0-5.5	1.34	.064	5.5-13.8	.17	.055	13.8-30.0	4.23	.80
1640 Marengo	42	Radial	30.0	1.44	0.634	.001	4.99	0-6.7	1.23	.077	6.7-15.7	.68	.083	15.7-30.0	.15	.10
		Tangential	30.0	2.46	0.657	.003	4.76	0-8.1	.36	.064	8.1-17.9	.58	.086	17.9-30.0	.91	.13
		Vertical	30.0	0.40	0.433	.004	2.78	0-5.6	1.83	.061	5.6-13.8	1.09	.069	13.8-30.0	.34	.09