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THE NONSTATIONARY MODEL OF SEISMIC EFFECTS FOR DESIGN OF STRUCTURES

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ABSTRACT

The main purpose of this papers is constructing of the statistical nonstationary model of seismic ground motions adaptable to design of structures for earthquake-resistance. In particular the model constructing in the form of artificial accelerograms with maximum acceleration values in the range of 100-200 sm/s^2 and for near earthquake zone with effective duration of about *5* s. is discussed in the paper.

KEYWORDS

Earthquakes; real accelerograms; statictic, model, artificial accelerograms; earthquake-engineering.

INTRODUCTION

To design new building elements, structures and important buildings for earthquke-resistance on the reliability theory level one needs statistical models of seismic effects. The paper (Dorofeyev,1988) proposed a new approach to creating of such statistical models with evalution of the model reliability. This paper has also formulated the main principles of a general model constructing of seismic effects that are reduced to the following procedure:
- the whole set of accelerograms to be analyzed that were recorded by the world observation network in various points of the Earth is subdivided into non-intersection subsets of accelerograms by a number of characteristics such as intensity, an epicentral distance, etc. with the aim of obtaining more uniform collections of data being basic for the analysis;
- uniform collections of data are analyzed, their statistical regulations are brought out and numerically realized in the form of seismic effects models for which the corresponding parameters of reliability are determined;
- all models obtained are combined into a general model of seismic effects applicable for the analysis of structures in any seismic conditions and not containing excessive information, i.e. by means of it one does not physically realize unreal accelerograms, this being a fault with many current models of seismic effects.

With this purpose the papers (Dorofeyev *at al.*,1990,1994) have attempted to analyze collections of real accelerograms recorded by the world observation network and characterized by the maximum values of accelerations in the range of 100 to 200 cm/s2 and formed from the records for a distant earthquake zone according to the formulas in the paper (Shteinberg,1986).The above papers present a statistical descrip-

Table 1. Quantitative data on the composition of initial information depending on the effective duration

Range of effective duration (s)	Conditional effective duration (s)	Number of accelerograms
< 3		7
3 - 7	5	26
7 - 12	10	11
12 - 17	15	7
17 - 22	20	1
22 - 27	25	1
27 - 32	30	4
32 - 37	35	3
> 37		3

tion of the data collection at constant values of two parameters connected with intensity and the epicentral distance (a distant earthquake zone). The present paper gives the analysis of data collection formed for same intensity, near earthquake zone with effective duration of about 5 s.

Let us determine the accekerogram in the general form as a continuous oscillating function whose discrete computer presentation is approximated by Fourier series in the frequency range of 0 to 25 Hz and that has certain statistical properties in distribution of Fourier coefficients.

The frequency range 0 to 25 Hz corresponds to the engineering range of seismic signals being of interest to earthquake-resistant construction, and in specific problems it can be narrowed on both sides. The indication of function continuity and oscillation is necessary due to discrete presentation of the function in practical expansions of Fourier series and due to requirement in its approximation in intermediate points for desing of structures for earthquake-resistance.

For accelerogram's Fourier coefficients the probability density functions were determined: the prevailing frequency F_{f0} ; the maximum value of Fourier coefficient for this prevailing value $F_A(f_0)$; dispersion describing the process of consecutive formation of Fourier coefficients $\sigma(f_o,f_i)$; correlation functions describing the process of consecutive formation of Fourier coefficients moving up in frequency $R_1(f_0,f_i.\tau)$ and moving down in frequency $R_2(f_0,f_i.\tau)$

The problem itself of forming a model of seismic effects for the specified data subset is reduced to two processes : the process of analyzing the initial information and obtaining analytical relationships describing its statistic, and the process of numerical realization of statistical processes described by these relationships in the form of artificially generated accelerograms collections.

DATA

As initial data 63 accelerograms recorded by the world observation network and meeting the above

Table 2. Information on accelerograms of the initial data collection with the conditional effective duration of 5 s

Earthquake name, place of recording, country	Data, time (hour, min.)	Component	Maximum acceleration (cm/s^2)
Lytle Creck, Cal., Wrighwood, USA	12.09.70. (06, 30)	S65E S25W	139 196
Friuli, Tarcento, Italy	11.09.76. (16, 31)	N90E	112
Helena,Montana, USA	31.10.35. (11, 38)	S00W S90E	143 142
Tien Shan, Hebei, China	31.08.76. (11,25)	NS EW	146 110
Tien Shan, Hebei, China	31.08.76. (11, 27)	NS EW	116 123
Tien Shan, Hebei, China	9.08.76. (06, 41)	NS EW	161 162
Nocera Umbra, Italy	21.05.79. (14, 34)	NS EW	141 109
Nocera Umbra, Italy	16.06.79. (19, 30)	NS EW	143 111
Norcia, N.-Mulano, Italy	22/27.09.79	EW	119
Norcia, N.- Altavillo, Italy	13.12.79/30.01.80	EW	179
Matsushiro, Wakaho, Japan	20.05.66. (09, 30)	NS EW	155 80
Imperial Valley, Cal.,El Centro, st. 6, USA	14.04.76. (10, 31)	N50E	137
Imperial Valley, Cal.,El Centro, st. 6, USA	20.06.75. (15,15)	S38E S52W	130 100
Eastern Yamanashi, Sakawagawa, Japan	16.06.76. (07, 36)	HB	141
Chubu, Hamana, Japan	16.03.83. (02, 27)	L T	187 137
San Francisco, Cal., USA	22.03.57. (11, 44)	N10E S80E	82 103

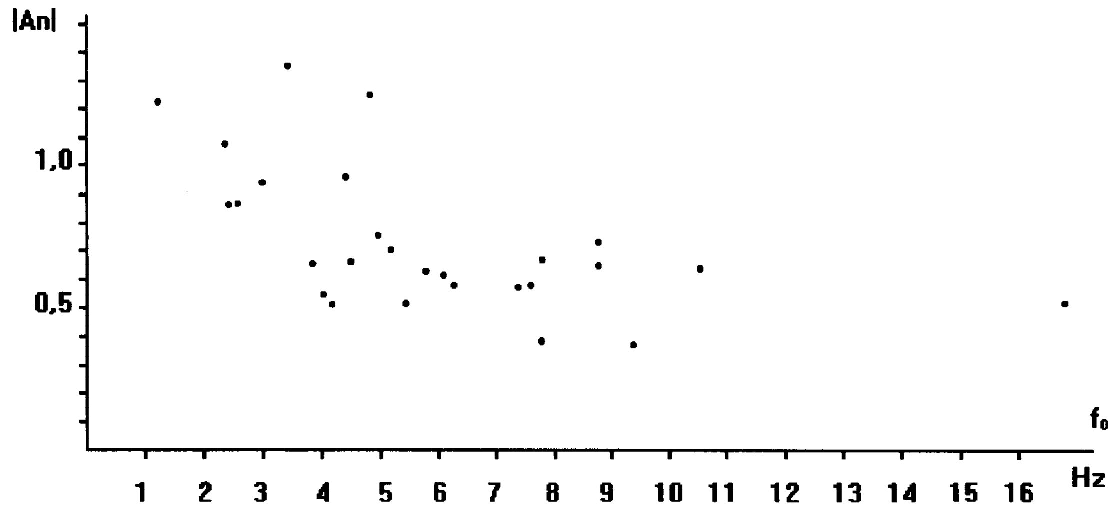

Fig. 1. The diagram of spread in maximum values of Fourier coefficients of accelerograms for prevailing frequences

requirements to a maximum acceleration value and an epicentral distance were used. Besides, with the purpose to eliminate the predominance of specific focal and geographical features, i.e. to obtain the data statistically more uniform by geography and foci, this collection did not include more than three accelerograms obtained from one earthquake or obtained at one geographic point. Table 1 presents data on the number of accelerograms in the collection with various effective durations. Effective duration here, as in papers (Dorofeyev, 1988), implies the duration of an accelerogram part with the acceleration values over 15 cm/s^2. Table 2 presents principal data on the records considered with conditional effective durations of 5 s, which contain records with effective durations in the range of 3 - 7 s.

CALCULATION RESULTS AND ANALYSIS

The main parameters describing the non-steady-state statistical process giving rise to artificially general accelerograms similar to real accelerograms of the initial collection to be analyzed are the probability density function of prevailing frequency F_{f0} ; the probability density function of Fourier coefficient maximum value for this prevailing frequency $F_A(f_0)$, where A - maximum value of Fourier coefficient at prevailing frequency f_0; dispersion describing the process of consecutive formation of Fourier coefficients $\sigma(f_o,f_i)$, where f_i - current frequency; correlation functions describing the process of consecutive formation of Fourier coefficients moving up in frequency $R_1(f_0,f_i.\tau)$ and moving down in frequency $R_2(f_0,f_i.\tau)$, where τ - frequency shift.

Fig.1 presents a diagram of spread in absolute values of Fourier coefficients for prevailing frequencies of accelerograms. It is clear from the figure that since the maximum values of Fourier coefficients fill the diagram non-uniformly then there exists a dependence of these maximum values on frequency.

Fig.2 presents the bar charts of prevailing frequencies of accelerograms. The probability density of accelerogram prevailing frequencies is well described by gamma-distribution

$$F_{f0} = \frac{\lambda^{\eta} f_0^{\eta-1} e^{-\lambda f_0}}{\Gamma(\eta)} \qquad (1)$$

where $\lambda = 1,4$; $\eta = 7,6$.

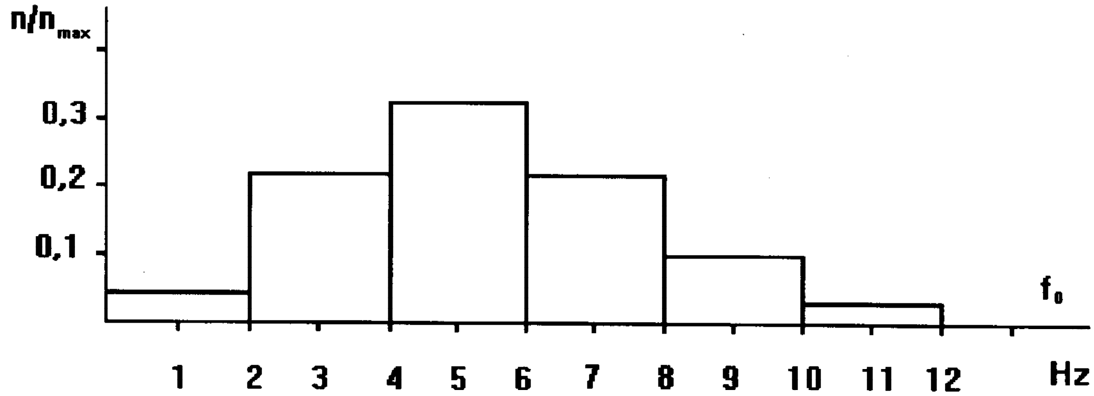

Fig. 2. The bar chart of accelerograms prevaling frequences

Paper (Dorofeyev *at al.*,1990) has established that the probability density of Fourier coefficients for the prevailing frequency at conditional effective duration of 10 s corresponds to the normal law. The studies of this fact for other conditional effective durations prove the established correspondence (Dorofeyev *at al.*, 1994). Table 3 presents mean values μ corresponding to these normal laws and dispersions σ for various ranges of prevailing frequences f_0.

Basing in the analysis of the data in this table we have obtained an expression for the probability density of Fourier coefficients at the prevailing frequency in the form of

$$F_A(f_o)= \frac{1}{\sqrt{2\pi\sigma(f_o)}} e^{-\frac{1}{2}[\frac{A-\mu(f_o)}{\sigma(f_o)}]^2} \qquad (2)$$

where $\mu(f_o) = 0{,}54 + 0{,}22/(f_0 - 2{,}1)$, $\sigma(f_0) = 0{,}0025 f_0^2 - 0{,}33 f_0 + 0{,}097$.

After defining the probabilities described by formulas (1) - (2) one can proceed to study the process of consecutive formation of Fourier coefficients, that is described by mean value $\mu(f_0,f_i)$, dispersion $\sigma(f_o,f_i)$ and two correlation functions $R_1(f_0,f_i.\tau)$ and $R_2(f_0,f_i.\tau)$ by means of which one describes consecutive formation of Fourier coefficients moving up in frequency from the prevailing one and moving down in frequency, respectively.

The analysis of accelerograms' Fourier spectra described in table 2 allowed to obtain the following relationships for the above mentioned parameters specific of the process of Fourier coefficients consecutive formation :

$$\begin{aligned} &\mu(f_o f_i)=0 \\ &\sigma(f_o f_i)=A(f_o)\, f_i^{\,a_1+a_2 f_o}\, e^{-2f_i} \\ &R_1(f_o ,f_i ,\tau)=\sigma(f_o ,f_i)\, e^{-\omega_1\tau}\cos[\alpha_3\tau], \\ &R_2(f_o ,f_i ,\tau)=\sigma(f_o ,f_i)\, e^{-\omega_2\tau}\cos[\alpha_4\tau], \end{aligned} \qquad (3)$$

Formulas (1) - (3) describe the whole non-steady-state statistical process giving rise to accelerograms

Table 3. The mean values and dispersions of normal laws of Fourier coefficient maximum values at the prevailing frequency

f_0	[1 - 3.8 Hz]	[3.8 - 6.5 Hz]	[6.5 - 11 Hz]
μ	1.04	0.61	0.57
σ	0.038	0.007	0.016

with maximum values of 100-200 cm/s^2 for the near earthquake zones, a part of which is the initial collection of real accltrograms analyzed. Therefore to create artificially generated accelerograms of this process one should realize it numerically.

In numerical realization of the problem put the three basic features were taken into account. The first one is connected with consecutive formation of Fourier coefficients. Fourier coefficients $\{A_n\}$ were formed on basis of the known (Bykov, 1971) algorithms for steady normal processes where μ,σ,R_1, and R_2 were used as defined by formulas (3).

The second feature is connected with construction of Fourier coefficients $\{B_n\}$ according to the available collection of Fourier coefficients $\{A_n\}$. The ratios of Fourier coefficients $\{C_n\} = \{B_n / A_n\}$ were studied. The collections of consecutive Fourier coefficients $\{A_n\}$ and $\{B_n\}$ of real accelerograms have a form of oscillating functions, while the maximum value of coefficient A in any train (a collection of consecutive coefficients of one sign from a minimum absolute value through a maximum to the next magnitude being minimum by its absolute value) coincides with the magnitude of coefficient B being minimum by its absolute value and vice versa. In this connection the process describing a simple ratio of coefficients B / A prossesses very high dispersion and does not allow to efficiently arrange construction of Fourier coefficients $\{B_n\}$ colltction according to the collection of Fourier coefficients $\{A_n\}$. At the same time the ratio of coefficients B and coefficients A' obtained by numerical differentiation of coefficients A is close to the constant value by means of which one can easily obtain a sequence of coefficients $\{B_n\}$.

The third feature is connected with summation of Fourier series. By its nature this procedure is refered to incorrect problems (Tikhonov, 1974), and due to this the summation is performed in the range of essential Fourier coefficients (approximate summation eliminating instablity in forming sums).

CONCLUSIONS

As a result a statistical description of the data collection studied at constant values of three parameters connected with intensity, the epicentral distance and duration are present. For accelerograms' Fourier coefficients the next characteristics were determined: the probability density functions of the prevailing frequency F_{f0}; the probability density functions of the maximum value of Fourier coefficient for this prevailing value $F_A(f_0)$; dispersion describing the process of consecutive formation of Fourier coefficients $\sigma\,(f_0,f_i)$; correlation functions of the precess of consecutive formation of Fourier coefficients moving up in frequency $R_1(f_0,f_i,\tau)$ and moving down in frequency $R_2(f_0,f_i,\tau)$.

The model obtained can be used in the actual design of structures for earthquake-resistance with minimum information concerning level of waiting intensity and tentative earthquake source zone locations the constructed model is adaptable to the design of structures for near zone earthquakes with maximum ground accelerations up to 200 sm/s^2 and effective duration of about 5 s.

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