A MODEL FOR SIMULATING GROUND MOTION

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ABSTRACT

Ground motion characteristics are first discussed from a qualitative view point. The scope of the paper is then formulated. Simulation techniques used in literature are briefly commented. A model for simulation of scalar or vectorial non-stationary motions is then described. The different wave trains (P-, S-, etc.) are explicitely considered, with a view on the influence of geologic conditions. The algorithms and flow charts used for programming are presented. Illustrative examples of applying the programs worked out are presented and results obtained are discussed from the view point of simulation techniques as well as of features of actual ground motions.

1. INTRODUCTION

The features of seismic ground motion that are the most significant from the view point of engineering purposes may be enumerated as follows: a seismic ground motion is random, non-stationary, vectorial (in an elementary sense if a single ground particle is considered, in a generalized sense if a set of particles is dealt with), and non-synchronous (in the sense that the dependence on time of various components is different). To simulate ground accelerations for the purpose of structural analysis, the features mentioned previously should be kept in view. The efforts of the authors have been oriented towards fulfilment of these requirements.

2. SOME REMARKS ON SIMULATION TECHNIQUES

Significant efforts have been devoted to the development and refinement of simulation techniques, and surveys given in [3] and [6] confirm this statement. It may be remarked in this view that research has been oriented mainly towards techniques that are satisfactory for scalar (one-point and one-direction) disturbances. Start points and methods that may be of direct use for the case of vectorial (multi-point and/or multi-direction) disturbances may be related to two main aspects: simulation on the basis of a model of earthquake generation mechanism, and simulation on the basis of some assumption on the local cross-correlations of different components. The first approach could be qualified as a rather rational one, since it attempts a representation of the features of the source and of the propagation path. The latter approach could be qualified as a rather empirical one. The work presented herein pertains basically to the latter approach, since it considers the features of the seismic disturbance at the site dealt with, without explicit regard to the earthquake generation and (long-distance) propagation mechanism.

3. THE MODEL AND THE ALGORITHM ADOPTED

A (scalar or vectorial) ground acceleration function $w_g(t)$ is considered to be a sum of the form

$$w_g(t) = a_I(t)w_I(t) + \ldots + a_Q(t)w_Q(t) \quad (1)$$

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The terms of the sum (1) are related to the phases of motion corresponding to the occurrence of different (P-, S-, ...) waves. The factors $w_q(t)$ (q = I ... Q) represent her (scalar or vectorial) stationary disturbances corresponding to each of the trains, while the factors $a_q(t)$ represent (scalar) deterministic envelopes. It is reasonable to assess some qualitative similarity of the envelopes $a_q(t)$ for P- and S- waves, since the different wave trains are due to a same source and to propagation of waves with different velocities.

The factors $w_q(t)$ are basically defined by means of their spectral densities $s_q(w;\omega)$ (the spectral densities will be scalar or matrix functions of ω for scalar or vectorial functions $w_q(t)$ respectively). It is reasonable to assess some qualitative similarity of the spectral densities. In cases when predominant circular frequencies β_q are determined essentially by local conditions, and when a charatteristic layer depth, H, can be defined, the similitude criterion $\beta_q H/c_q$ (c_q: wave propagation velocity for the q-th train) should be practically invariant for the different wave trains.

The canonic representation of stationary random functions permits to approximate any scalar stationary function $w_q(t)$ by means of a sum

$$w_q(t) = b_{q1}\cos(\omega_1 t - \varphi_1) + \dots + b_{qR}\cos(\omega_R t - \varphi_R) \qquad (2)$$

where ω_r (r = 1 ... R)are equidistant circular frequencies populating the interval that is significant for the q-th wave train, φ_r are random initial phases, and b_{qr} are amplitudes determined on the basis of the spectral density $s_q(w;\omega)$.

To introduce a similar representation in case of vectorial functions $w_q(t)$, the components of which are denoted by $w_{qk}(t)$ (k = 1 ... K), two alternative approaches are adopted: the correlation tensor (TC), and the phase lag (LP) approaches. These approaches have been used already in [4] for the case of (one-train) stationary ground disturbance. In the first case (TC) the current term $b_{qr}\cos(\omega_r t - \varphi_r)$ of the expansion (2) is replaced by a vectorial term $b_{qrk}\cos(\omega_r t - \varphi_{rk})$ that corresponds to a correlation matrix $s_{qkl}(w;\omega_r)\Delta\omega$ ($\Delta\omega = \omega_{r+1} - \omega_r$; $s_{qkl}(w;\omega_r)$: the assumed spectral density matrix). To obtain the required terms $b_{qrk}\cos(\omega_r t - \varphi_{rk})$, K non-correlated sinusoidal functions are basically generated (this can be obtained in case of uniform random distribution of the initial phases φ_{rk} in the interval $[0, 2\pi)$). The non-correlated functions are then combined linearly so as to obtain the required correlation matrix. The technique is referred to in [6] too. Some discussion on cross-correlation factors is given in [5]. For two degrees of freedom corresponding to parallel directions, it is reasonable to assess that the cross-correlation factors are close to unity for small values $\omega_r d/c$ (d: mutual distance of points; c: wave propagation velocity) but are vanishing for high values of this criterion. In the secondcase (LP) the spectral density $s_q(w;\omega)$ is defined basically for a refernce (translational) component $w_{qk*}(t)$ of the ground disturbance. A wave propagation phenomenon is defined on this basis, by adopting some assumptions on the wave propagation mechanism. It is reasonable to assess that each sinusoidal component of the wave prophenomenon, corresponding to the expansion (2) in this case has a random propagation direction (in view of the complexity of reflection-refraction phenomena). The different natures of the wave trains dealt with lead to different relationships between propagation and oscillation directions for the different trains (in case of infinite medium, these directions coincide for P- waves, but are orthogonal for S- waves for instance). The assessments on propagation directions and on propagation velocities permit to generate the phase lags for the motions of various points.

To work out (FORTRAN) subprograms for the simulation of non-stationary ground accelerations, an initial step and a current generation step have been considered in any case,(fig. 1). These steps may refer, as a principle, to the simulation of ground motion, or of the ground and structure motion. In the first case, the results of simulation must be stored, while in the latter one they are used directly for the analysis of structural oscillations. The current generation step is represented in fig. 2 (subroutines SIGANS and SIGANV for scalar and vectorial disturbance, respectively). The initial step (subroutine SIIANS) is represented in fig. 3 for scalar disturbances and in fig. 4 for vectorial disturbances. The hexagonal box of fig. 4 is detailed in fig. 5 for the TC model (subroutine SIIANC) and in fig. 6 for the LP model (subroutine SIIAND). The initial step (subroutines SIIANS, SIIANC, SIIAND) defines basically the spectral distribution of the disturbance for any of the wave trains cosidered, while the current generation step (subroutines SIGANS, SIGANV) represents a routine computation step.

4. ILLUSTRATIVE EXAMPLES

Some examples of simulation are represented in fig. 7 (model TC) and in fig. 8 (model LP). It is not interesting to give separately an example of a scalar disturbance, since this one is represented by any of the components of the vectorial disturbances referred to. One has considered in any case a set of three points located on the Ox axis, at abscissae of o, 5o, 1oo m. The wave propagation velocities c_p = 1ooo m./s. c_s = 5oo m./s. have been introduced in computations in any case. The accelerations along the orthogonal horizontal axes Ox and Oy have been dealt with. The expression

$$s_q(w;\omega) = \sigma^2(w_q)\,\frac{\alpha_q}{\pi}\,\frac{\omega^2+\alpha_q^2+\beta_q^2}{\omega^4+2(\alpha_q^2-\beta_q^2)\,\omega^2+(\alpha_q^2+\beta_q^2)^2} \qquad (3)$$

has been assumed for a reference translational component in any case ($\sigma(w_q)$: r.m.s. acceleration for the q-th train; β_q: predominant circular frequency; $\beta_q/\alpha_q = 4$ in any case: a selectivity measure). The cross-correlation factor $\rho(a)$ has been defined (in case of the TC model) for two parallel directions by the expression

$$\rho(a) = \exp(-.5a)[\cos a + .5\sin a]; \quad (a = \omega\Delta x/c_q) \qquad (4)$$

It has been assumed to vanish in case of orthogonal directions. The distribution of propagation directions has been adopted (in case of the LP model) as a uniform one in the interval $[o, 2\pi)$ in the horizontal plane. The simulation has been carried out for any of the models for two-train (P-,, S-, waves) motions and two different sets of values of α_q and β_q (these values are given in fig. 7 and in fig. 8). The envelopes for the wave trains had the form $a_q t*\exp[-b_q(t-t_q)]$ in any case (the maximum value for S- waves was the double of that chosen for P-waves).The duration of motion was of 2o s. The simulation has been carried out in any case by using 1oo equidistant values ω_r occurring in expression (2) ($\omega_{r+1} - \omega_r = 1\ s.^{-1}$).

A brief discussion of the results represented in fig. 7 and in fig. 8 may be of interest. The decrease of cross-correlations with increasing distance and with increasing oscillation frequency is obvious. Bothaspects can be concentrated in the dependence on the non-dimensional criterion a,(4). The qualitative similarity of results furnished by the models TC and LP is obvious. The quantitative assumptions on wave propagation velocities and on predominant frequencies fall in a realistic range. The non-synchronous character of ground motions at different points of contact between ground and structures is illustrated and confirmed by the results obtained. This confirmation should be considered as a rather qualitative one, since the cross-correlations tend to be underestimated for both models. The expression (4) used for the TC model overlooks the tendency to stronger correlation implied by a vertical, or almost vertical, direction of propagation, that is often present. The assumption on the distribution of directions adopted for the LP models tends to introduce a distortion in the same sense. These distortionsare equivalent with the consideration of too low conventional propagation velocities in the models defining cross-correlations. Nevertheless, it may be estimated that the distortions referred to do not change the order of magnitude of the correlation parameters. It should be concluded again that the non-synchronous character of ground motion at different ground-structure contact points must not be overlooked in engineering analyses.

REFERENCES

1. J. Ferry Borges, V. I. Bunê, C. A. Cornell, L. Esteva, V. Kárnik, H. Kobayashi — Earthquake Parameters for Engineering Planning and Design. UNESCO Conf. on Assessment and Mitigation of Seismic Risk, Paris, 1976.

2. R. Levy, F. Kozin, R. B. B. Moorman — Random Processes for Earthquake Simulation. Proc. ASCE, EM 2, 1971.

3. N. M. Newmark, E. M. Rosenblueth — Fundamentals of Earthquake Engineering. Prentice Hall, Englewood Cliffs, N.J.

4. H. Sandi — ALGOL Procedures for Simulating Stationary Random Ground Motions. Proc. Conf. on the Seismic Analysis of Structures, Iaşi, 197o.

5. H. Sandi — Estimates of Non-Synchronous Seismic Disturbances. Proc. 5-th Europ. Symp. on Earthquake Engineering, Istanbul, 1975.

6. M. Shinozuka — Digital Simulation of Ground Acceleration. Proc. 5 WCEE, Rome, 1973.

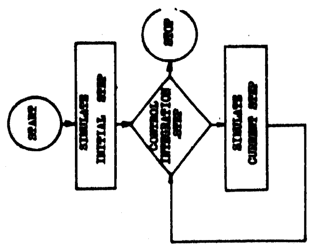


Fig.1

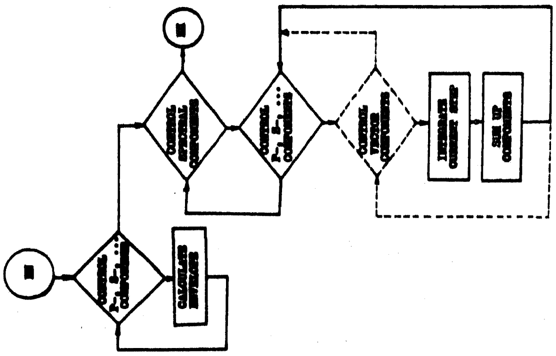


Fig.2

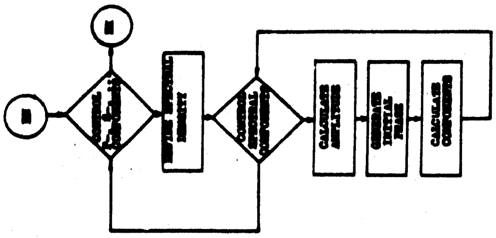


Fig.3

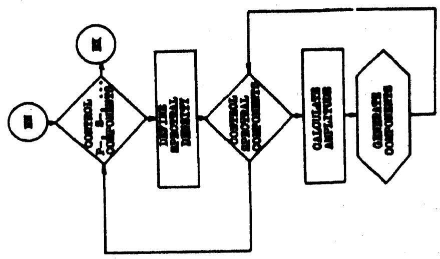


Fig.4

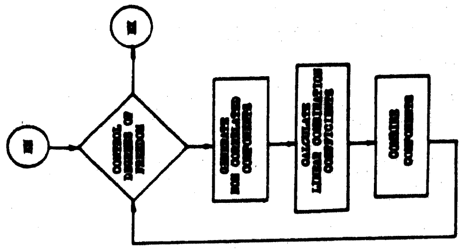


Fig.5

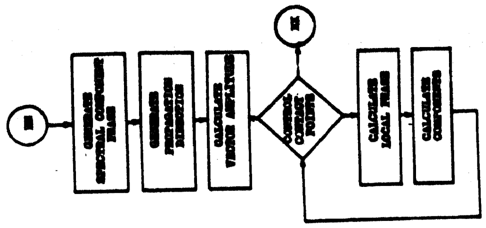
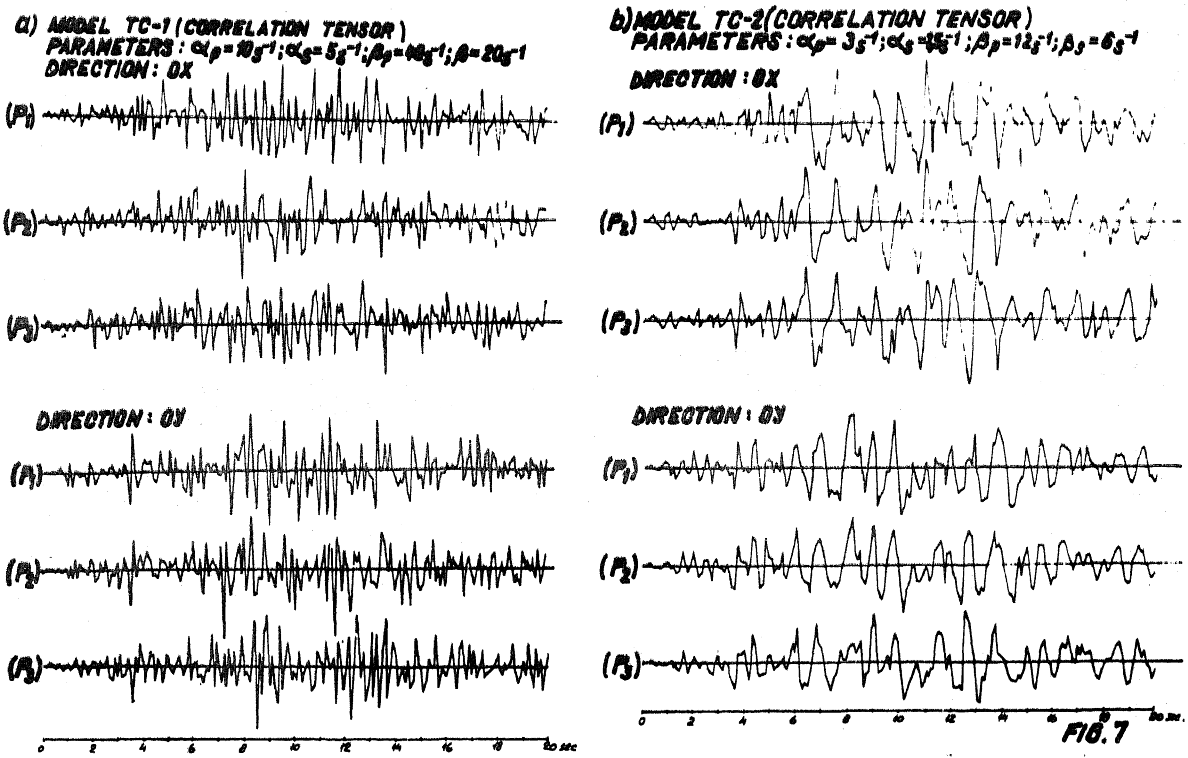
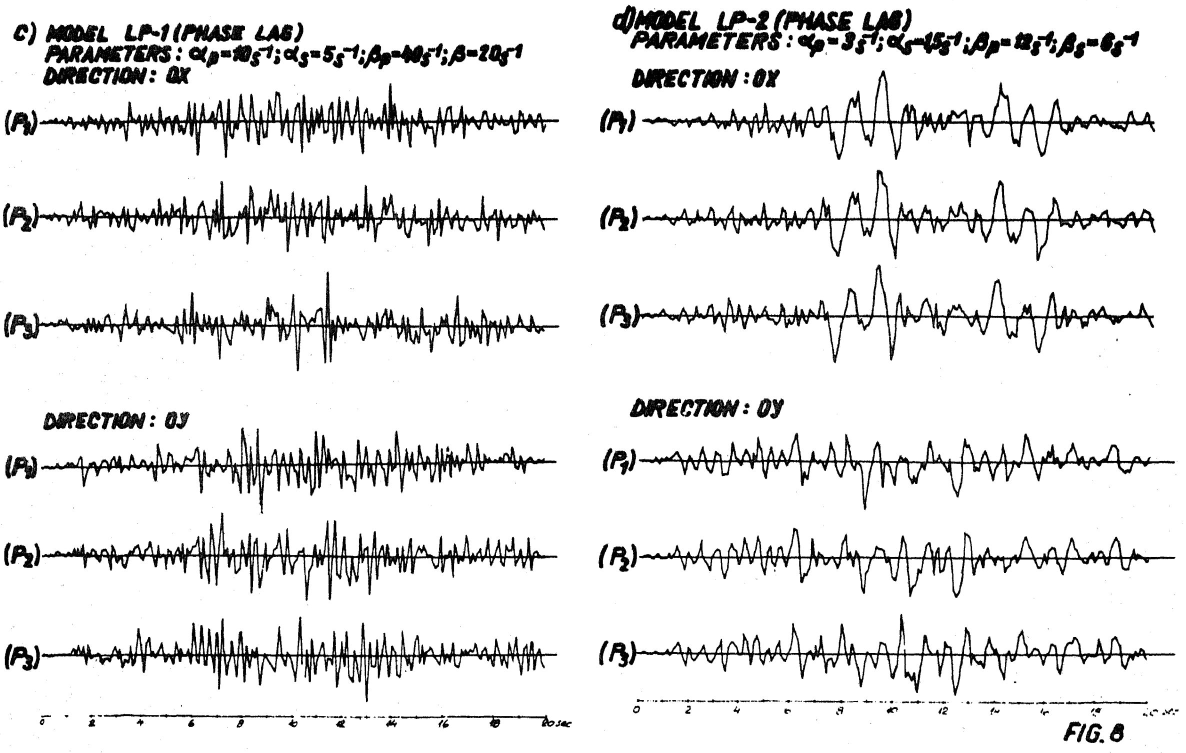


Fig.6



a) MODEL TC-1 (CORRELATION TENSOR)
PARAMETERS : α_p=10 s-1; α_s=5 s-1; β_p=40 s-1; β=20 s-1
DIRECTION : OX
(P1)
(P2)
(P3)
DIRECTION : OY
(P1)
(P2)
(P3)
0 2 4 6 8 10 12 14 16 18 20 sec
b) MODEL TC-2 (CORRELATION TENSOR)
PARAMETERS : α_p=3 s-1; α_s=1.5 s-1; β_p=12 s-1; β_s=6 s-1
DIRECTION : OX
(P1)
(P2)
(P3)
DIRECTION : OY
(P1)
(P2)
(P3)
0 2 4 6 8 10 12 14 16 18 20 sec

FIG. 7



c) MODEL LP-1 (PHASE LAG)
PARAMETERS : α_p=10 s-1; α_s=5 s-1; β_p=40 s-1; β=20 s-1
DIRECTION : OX
(P1)
(P2)
(P3)
DIRECTION : OY
(P1)
(P2)
(P3)
0 2 4 6 8 10 12 14 16 18 20 sec
d) MODEL LP-2 (PHASE LAG)
PARAMETERS : α_p=3 s-1; α_s=1.5 s-1; β_p=12 s-1; β_s=6 s-1
DIRECTION : OX
(P1)
(P2)
(P3)
DIRECTION : OY
(P1)
(P2)
(P3)
0 2 4 6 8 10 12 14 16 18

FIG. 8