REFINEMENTS IN CHARACTERIZING GROUND MOTIONS

H. Sandi*

1. INTRODUCTION

To measure in some way ground motions is a basic need of engineering activities related to costruction in seismic areas. This need has been at the origin of various measures introduced to date, ranging from a unique scalar parameter (like intensity for local ground motion, or magnitude for an earthquake as a whole) up to sophisticated systems of parameters proposed during latter years. Intensity (like MM or MSK), response spectra, spectrum intensity, Fourier spectra, velocity response envelope spectra [2], [3], [5], [6], [7] represent some of the most important attempts of characterizing the various aspects of the multifaceted phenomenon of ground motion.

This paper presents some further developments of the system dealt with in [1o], aimed to measure in a flexible manner, ground motions. After presenting the logical construction of the ground motion measuring system, emphasis is put on its heart, the measure of local motion destructiveness. The results of some illustrative calculations are given. These calculations relate to the INCERC, Bucharest, strong motion record of the Romania, 4 March 1977, earthquake (the difficulties met when attempting to evaluate that event by means of classical tools like MSK intensity, or Richter magnitude, have been at the origin of developments of [1o]).

2. CONSTRUCTION OF THE GROUND MOTION MEASURING SYSTEM

The system of measuring ground motions has been costructed as follows:

1. A tensorial destructiveness measure, $D_{ij}(f)$, (i,j=1,2,3: directions of axes of coordinates; f: frequency) is introduced as a basis of further developments. This measure is proportional to the square of motion amplitude (and to kinetic energy induced to structures), and is sensitive to direction and frequency. The deteailed definition of $D_{ij}(f)$ is dealt with in the next paragraph of the paper.

2. The destructiveness tensor permits to define various additional parameters, like spherical destructiveness, $D_s(f)$, horizontal plane destructiveness, $D_h(f)$, vertical destructiveness, $D_v(f)$, or direction oriented destructiveness, $D_\alpha(f)$:

$$D_s(f)=\sum_i^{1,3} D_{ii}(f);\quad D_h(f)=\sum_i^{1,2} D_{ii}(f);\quad D_v(f)=D_{33}(f);\quad D_\alpha(f)=\sum_{i,j}^{1,3}\alpha_i\alpha_j D_{ij}(f) \qquad (1)$$

(α_i: cosines of direction α).

3. Any of the destructivemesses referred to may be averaged over some frequency interval (f',f"). The averaging is carried out using a weighting function that is consistent with a distribution (of structures to be affected by a motion) that is uniform with respect to the logarithm of frequency (and, symmetrically, of period) of oscillation:

$$\overline{D}(f',f'')=\frac{1}{\ln(f''/f')}\int_{f'}^{f''}D(f)\ df/f=\frac{1}{\ln(T'/T'')}\int_{T''}^{T'}D(1/T)\ dT/T \qquad (2)$$

(where fT=1). Besides the averaged destructiveness, a cumulative (spherical) destructiveness,

$$E_s(f',f'')=\int_{f'}^{f''}D_s(f)\ df/f=\overline{D}_s(f',f'')\cdot\ln(f''/f'), \qquad (3)$$

*INCERC (Building Research Institute), Bucharest.

may be used.

4. The selection of a fixed interval, (f_{min}, f_{max}), permits to define an engineering size of ground motion, $E_s(f_{min}, f_{max})$. The values f_{min} =.25 Hz and f_{max}=16. Hz appear to be reasonable in this view.

5. An averaged (engineering, spherical) intensity may be defined on the basis of the averaged (spherical) destructiveness,

$$\overline{I}_s(f', f'') = I_o + \log_4 \overline{D}_s(f', f''). \qquad (4)$$

Specific (spherical) intensity, $I_s(f)$, may be defined in the same way on the basis of $D_s(f)$. The engineering (spherical) intensity of the motion may be defined as $\overline{I}_s(f_{min}, f_{max})$. The use of $\log_4$ in (4) provides compatibility with classical intensity scales. Note here that $\overline{I}_s(f_{min}, f_{max})$ may be defined also on the basis of $E_s(f_{min}, f_{max})$, in an equivalent way.

6. The ground motion can be characterized now by a vector of averaged intensities. For instance, the adoption of values $f_1 = f_{min}$; $f_{k+1} = f_k * 2^{1/2}$; .. $f_{13} = f_{max}$, leads to a twelve-component vector, $I_k^{(v)} = \overline{I}_s(f_k, f_{k+1})$.

Other parameters, like normalized destructiveness, d(f), engineering size of an earthquake (as a whole), H_s, and engineering magnitude, M_s, have been also defined in [1o].

The system of measuring ground motions proposed is thus based on accelerograms, provides flexibility, may be correlated with destructive effects on structures, is related to parameters used in engineering, permits to evaluate the contribution of direction or frequency components to the overall violence, may be correlated with classical intensity, introduces a simple relationship between local violence and size of an earthquake, and may be used as a skeleton for macroseismic surveys.

3. DESTRUTIVENESS DEFINITIONS

The definition of the tensor $D_{ij}(f)$ is of central importance for the measurement system proposed. The main requirements for a suitable definition of this tensor are: sensitivity with respect to direction and to frequency, some kind of additivity with respect to the contributions of directions and frequencies, fair correlation with destructive effects of strong motion. Analyses carried out have shown that it is desirable to adopt more proper definitions than those proposed in [1o]. The definition

$$D_{ij}(f) = \int v_i^{abs}(f,n;t) v_j^{abs}(f,n;t) \, dt \qquad (5)$$

(where the factor $\underline{f}$ of the definition $D^{(2)}(f)$ of [1o] has been dropped) appears to be a suitable one. The function $v_i^{abs}(f,n;t)$ represents here the absolute velocity of a SDOF system (f: natural undamped frequency; n: critical damping fraction) subjected to the ground motion along the axis $\underline{i}$. The integration is carried out over the whole duration of the motion. The property

$$\sum_{i,j}^{1,3} \alpha_i \alpha_j D_{ij}(f) \geq 0 \qquad (6)$$

for any direction of cosines α_i may be easily proven.

The adoption of the definition (5) appears to be a convenient solution, due to several reasons: it relies on absolute velocities and so, it is related to kinetic energy and inertia forces; it gives a picture of loading along various directions (for any couple (f,n) destructiveness ellipsoids, ellipses, etc. can be drawn); it gives a picture of the spectral content of motion; it provides additivity with respect to directions and frequencies. A value n=.o5 appears to be reasonable [1o]. The calibration of the constant I_o of (4) depends on the definition of $D_{ij}(f)$. In case the definition (5) is adopted, and velocities are measured in m/s, a value I_o=8 is likely to lead to values of $\bar{I}_s$ that are close to classical (MM, MSK) intensities. Systematic analyses should bring more accuracy .

A computer program has been developed by the author in order to determine the destructiveness tensor for a given sequence of frequencies.

4. ILLUSTRATIVE EXAMPLE

The SMAC-B acceleration record obtained at INCERC-Bucharest on 4 March 1977, represented in fig. 1, has led, for the horizontal components, to the response spectra of absolute accelerations (for n=.o5) represented in fig. 2. Specific intensities (not averaged over a frequency interval), calculated on the basis of expressions (4) and (5) are represented in relative terms (without paying attention to the constant I_o) in fig. 3 for the two horizontal components (I_{NS} and I_{EW}) and for the sum of their contribution (only horizontal plane intensities, I_h, and not spherical intensities, are given in the figure). The contribution of these components depends on frequency. The horizontal plane destructiveness ellipses are represented for some frequencies in fig. 4. They permit to illustrate the most dangerous directions for various frequencies.

* * *

ACKNOWLEDGEMENT

The author is indebted to his colleague S. Minea, for her help in testing and running the computer program developed.

REFERENCES

1. T. K. Caughey — Non-Stationary Random Processes. ch. 3 in: Random Vibrations, vol.2 (ed. S. H. Crandall), MIT, 1963.

2. L. Esteva — Seismicity. ch. 6 in: Seismic Risk and Engineering Decisions (ed. C. Lomnitz and E. Rosenblueth). Elsevier, Amsterdam-Oxford-New York, 1976.

3. G. Housner — Strong Ground Motions. ch.4 in: Earthquake Engineering (ed. R. Wiegel). Prentice Hall, 197o.

4. E. Iordăchescu, T. Zorapapel, D. Marcovici, G. Danci — Statistical Survey of the Performance of one Standard-Design Type of High-Rise Reinforced-Concrete Shear-Wall Apartment Building, in Bucharest, during the March 4, 1977, Romania Earthquake. Proc. US National Conference on Earthquake Engineering, Stanford University, Palo Alto, 1979.

5. S. V. Medvedev — Engineering Seismology (in Russian). Gosstroyizdat, Moscow, 1962.

6. C. P. Mortgat, H. Shah — An Intensity Scale for Earthquakes. Proc. 5 ECEE, Istanbul, 1975.

7. V. Pérez — Peak Ground Accelerations and their Effects on the Velocity Response Envelope Spectrum as a Function of Time, San Fernando Earthquake, February 9, 1971. Proc. 5 WCEE, Rome, 1973.

8. A. Poceski — On the Intensity of Strong Motion Earthquakes. Proc. 5 ECEE, Istanbul, 1975.

9. H. Sandi, G. Şerbănescu, T. Zorapapel — Lessons from the Romania, 4 March 1977, Earthquake. Proc. 6 ECEE, Dubrovnik, 1978.

1o. H. Sandi — Measures of Ground Motion. Proc. US National Conference on Earthquake Engineering, Stanford University, Palo Alto, 1979.

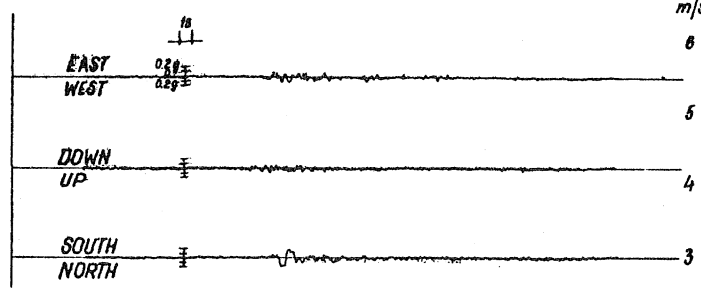

Fig 1

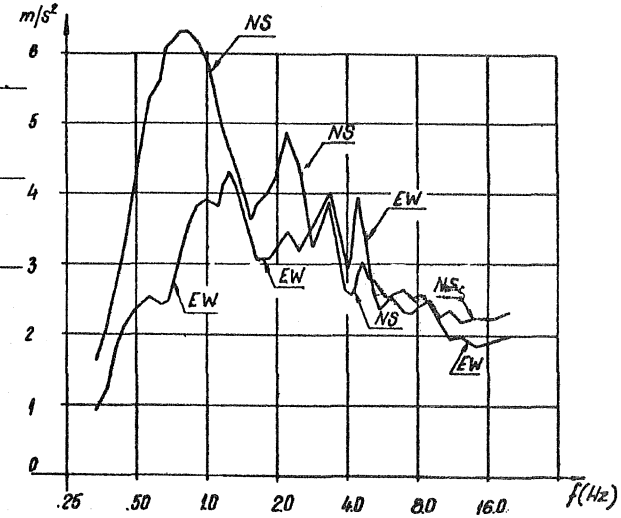

Fig.2

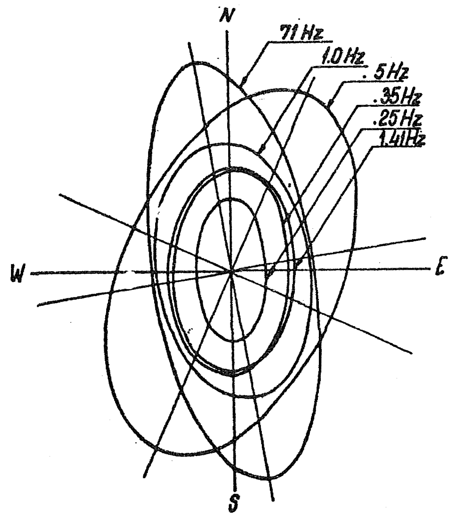

Fig. 4

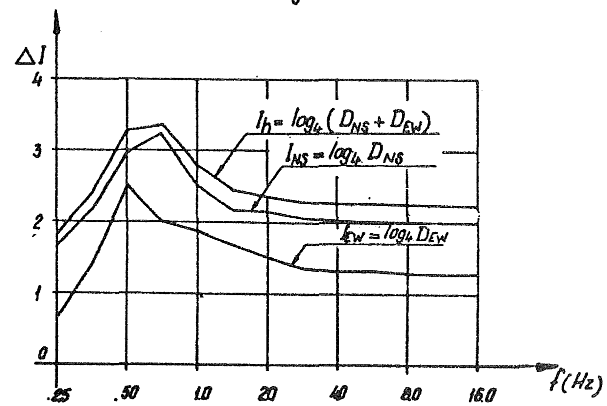

Fig.3