Characterization of Local Seismicity and Simulation of Accelerograms

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Abstract

Several ground acceleration time histories are requested for the safety analyisis of complex structures in seismic zone. Generally the lack of recorded data makes the numerical simulation from a stochastic model the only way to obtain significant statistical samples of accelerograms. In this paper a simple stochastic idealization of the seismic action is considered: the power spectral density function of the stationary process is assumed to be described by the Kanai-Tajimi model with random basic parameters. Response spectra obtained from two samples of recorded earthquakes are compared with the ones derived from the corresponding samples of simulated accelerograms. For this purpose a suitable normalization technique is introduced. The aim is to point out the capability of the simulation procedure in carrying out time histories able to describe the actual seismicity of the choosen site.

1. Introduction

A paper published in 1975 |1| supported the thesis that the earthquake event is not significant in the risk assessment of a nuclear power plant. However successive studies showed that the risk associated with seismic events is a very important part of the total risk. Nevertheless, the stochastic nature of such external action was ignored, the ground motion being defined by a suitable design spectrum very useful for performing simple linear dynamic analyses |2|. This approach to the problem led to simulate , when they were necessary, ground acceleration time histories that fit a particular design spectrum |12|.

The recording and the analysis of the data relevant to the earthquakes are presently becoming very effective and reliable. A particular site can therefore be characterized by the analysis of a sample of recorded accelerograms provided it exists. Otherwise stochastic models have to be introduced in order to by-pass the lack of data.

The purpose of this paper is to point out the differencies that can be observed in term of structural response following the two approaches at the same site. For this aim two sites with enough records to have a statistically significant sample are choosen. The same stochastic model with the two sets of parameters calculated on the basis of the two samples of records is then introduced for the two sites. Samples of simulated time histories are generated from the relevant stochastic models. The comparison between recorded and simulated seismicity is carried out in term of response spectra.

2. Groud motion: analysis and idealization

2.1 Characterization of eathquakes and processing of records

A natural groud motion can be regarded as a segment of a stationary stochastic process of limited duration S_o |3|. A simple procedure for estimating the equivalent duration S_o of the strong motion has been proposed in |3| where S_o is related to the root mean square (r.m.s.) σ_o of the ground acceleration a(t) as follows:

$$\sigma_o = \left[\int_o^d a^2(t)\ dt\ /\ S_o\right]^{\frac{1}{2}} = (I_o/S_o)^{\frac{1}{2}} \tag{01}$$

In Eq.(01) d is the length of the digitized accelerogram (in seconds) and I_o denotes the Arias intensity. S_o and σ_o can be obtained solving the system:

$$\begin{cases} I_o = \sigma_o^2\ S_o \\ a_{max} = [2\ \ln\ (2\ S_o/T_o)]^{\frac{1}{2}} \cdot \sigma_o \qquad S_o \geq 1.36\ T_o \end{cases} \tag{02}$$

where a_{max} is the peak recorded acceleration and T_o is the predominant period of the earthquake motion. An estimation of T_o can be done by counting the zero crossings of the record |3||4|.

In the frequency domain the ground motion can be represented in terms of the power spectral density function. Following the Kanai - Tajimi model |5|, the frequency content of earthquakes can be well described by the function:

$$G(\omega_i) = \frac{[1 + 4\xi_g^2\ (\omega_i/\omega_g)^2]\ G_o}{[1-(\omega_i/\omega_g)^2]^2 + 4\xi_g^2(\omega_i/\omega_g)^2} \tag{03}$$

where the parameters ξ_g, ω_g and G_o have to be evaluated from earthquake records |6|.

From the single record one can obtain an estimation of $G(\omega_i)$ by computing the Fourier amplitude spectrum (F.a.s.) of the ground acceleration $A(\omega_i)$:

$$G(\omega_i) = (1/\pi\ S_o)\ \left|\int_o^d a(t)\ e^{-i\omega t}\ dt\right|^2 = (1/\pi S_o)\,|A(\omega_i)|^2 \tag{04}$$

However, in order to have reliable estimation of Eq.(03), it is better to make use of the method of spectral moments. This method has been used by several researchers |6||7|: it performs frequency domain analysis on the basis of the knowledge of the first few spectral moments of a Power Spectral Density (PSD) function, the j-th spectral moment λ_j being defined by:

$$\lambda_j = \int_o^\infty \omega^j\ G(\omega)\ d\omega \tag{05}$$

The procedure is based on the calculation of the Kanai-Tajimi (K-T) parameters in such a way that the spectral moments of the power spectrum associated with the record under investigation, are the same of those of the K-T PSD function. In this way ξ_g, ω_g and G_o can be computed by writing three characteristic parameter of the record excitation (central frequency ω_c, shape factor δ and r.m.s. σ_o) as functions of the spectral moments |6|.

The F.a.s. are calculated by Fourier transformation of the equispaced record of the ground acceleration. However it is well known that all the handlings needed to obtain the digitized earthquake from the record affect in some way the frequency content of the strong motion. It follows that some filtering corrections of the F.a.s. could be adopted for the evaluation of the K-T parameters. Since these corrections have been avoided in previous studies, it is not introduced in the present paper for making possible numerical comparisons. The authors however have pointed out differencies of some % between the characteristic parameters of the excitation calculated from the uncorrected and the corrected records.

2.2 Record processing

Filtering accelerogram from the noise introduced by the operative techniques of the digitization procedure can be performed in time |8| or in frequency domain |9|. The latter method has been adopted in this paper everywhere processed records were required. It consists in the development of the following operations:

i) equispacing of the raw data file of the time history

ii) calculating the F.a.s. $A(\omega)$ of the record

iii) filtering in the frequency domain of $A(\omega)$

iv) riconversion in the time domain by the inverse Fast Fourier Transform (F.F.T.)

The filtering is done by a band-pass filter with cut-off and roll-off frequencies in the range 0.25÷0.5 Hz on the left side and in the range 25÷27 Hz on the right side. It takes account also of instrument and baseline correction.

A processed accelerogram represents the starting point to obtain response spectra. The response spectrum is regarded here as an expressive way for a global overview of the influence of the various earthquake aspects affecting the response of a structural system. However these spectra have to be normalized in order to be compared. In this paper two approaches are followed to pursue this result. The first consists in applying a scaling factor to the accelerograms to obtain the same desired peak acceleration and then in calculating the corresponding response spectra to be compared. The second approach consists in the calculation of the response spectra directly from the processed accelerograms. Then they are normalized by a procedure making use of different scaling factors for different frequency ranges |10|. The specified ranges of frequency are: 1) 0.071÷0.2 Hz (displacement region), 2) 0.2÷2 Hz (velocity region), 3) 2÷8.5 Hz (acceleration region). The corresponding normalizing factors are defined in terms of the spectra intensities (SI_i) by:

$$SI_1 = \int_{.08}^{.24} \frac{S_v(\beta,f)}{f^2}\, df \quad ; \quad SI_2 = \int_{.5}^{3.5} \frac{S_v(\beta,f)}{f^2}\, df \quad ; \quad SI_3 = \int_{5.4}^{35} \frac{S_v(\beta,f)}{f^2}\, df \qquad (06)$$

S_v represents the response spectrum expressed as a function of the frequency f and the damping ratio β.

2.3 Ground motion idealization

The treatment of section 2.1 has implicitly accepted that the ground motion can be idealized by stochastic models. In particular this model is frequency invariant, due to the fact that Eq.(03) is independent on the time. Conversely the assumption of stationarity can be released by introducing a suitable modulating function |11||12|. A more accurate description of the randomness of the ground motion can be obtained by regarding also the parameters of the model as random |13||14|. In particular the natural frequency of the ground ω_g, the soil effective damping coefficient ξ_g and the intensity of the ideal white noise excitation at the bedrock G_o can be usefully assumed to be jointly lognormally distributed. According to |14|, the modulating function I(t) is then built up by the following three envelopes:

1) a parabolic one in the form $I(t)=(t/t_1)^2$ where $t_1=0.55\ S_o$ and defined in the range $0 \div t_1$
2) a segment of levelling time with constant unitary intensity and length S_o
3) an exponential part $I(t)=e^{-c(t-t_2)}$ where $t_2=t_1+S_o$ and c is a coefficient of value 0.15, defined in the range $t \geq t_2$.

Starting from the previous model a single realization of the process can be obtained by classical procedures |15||16|. In this paper the authors have adopted a frequency domain procedure where the single realization $x_s(t)$ is obtained by the knowledge of the smoothed and estimated P.S.D. function $G(\omega)$ given by Eq.(03) associated with the underlying stationary stochastic process and by appropriate lumping of the function $G(\omega)$ in discretized frequency values. Each lumped area is then assumed to represent the amplitude of series of harmonic functions with random phase angle ϕ_i uniformly distributed over the frequency range $(0, 2\pi)$.

The authors are aware that more sophisticated models are available |17||13||19|, but further investigations in this direction will be performed in future works.

3. A numerical example

The selection of the record used in this example has been done on the basis of the Italia data bank of digitized earthquakes |20|. The two sets of samples records here choosen have been selected looking at the size of the sample of accelerogram recorded in the same station and at the value of the peak ground acceleration requested to be at least equal to 0.028 g. Following this way a sample of fifteen accelerograms recorded in Forgaria-Cornino (F-C) has been selected with another sample of ten records in Tolmezzo (T).

The numerical computations are perforemed on the N-S component of the selected records. The characterization of the earthquakes and the identification of the meaningful parameters to be used in the stochastic model (ξ_g, ω_g, G_o, S_o) are performed for the sets of records according to the procedures just described in sections 2.1 and 2.2 and the correlation coefficients relevant to the same quantities obtained.

The simulation procedure of the accelerograms is based on the stochastic model described in 2.3 and codified in a computer program obtained with some improvements of the main code SIMQKE |12| . The above mentioned parameters were assumed to be jointly lognormally distributed and their correlation taken into account|21|.Two samples of artificial earthquakes were generated using this model: the first one includes fifteen accelerograms obtained on the basis of the data relevant to F-C; the second one considers ten records obtained for T.

The correlation analysis on the fundamental parameters describing the contemporary earthquakes recorded at the two stations showed that both S_o and the peak acceleration are strictly correlated, while this observation is not valid for the K-T parameters. So the two samples have been regarded to be independent. Then two ways have been followed in calculating the response spectra, as described in 2.1. Once the spectra were calculated, statistics on homogeneous sets of responces have been performed. Fig.1.a shows the mean response spectrum and the mean plus one standard deviation (s.d.) obtained by scaling the corrected accelerograms to a prefixed value of the peak acceleration ($\bar{a}_{max}$=0.1 g) relevant to T, while in Fig.2.a the results got following a similar procedure for F-C are summarized. Fig.1.b and 2.b refer to the outcome obtained for the stations considered by the simulation procedure, taking into account the correlation of the characteristic parameters, with G_o=1 and $\bar{a}_{max}$=0.1 g. The statistics performed for the response spectra obtained from the processed accelerograms and then normalized according to the procedure of spectral intensities (see 2.1) are summarized in Fig. 3.a and 4.a respectively for T and F-C. In parallel way Fig. 3.b and 4.b show the simulation procedure results when the correlation between the parameters and a simulated value of G_o have been taken into account. For this numerical example the damping ratio β is always assumed equal to 0.02.

4. Conclusions

By observing the response spectra relevant to the accelerograms with $\bar{a}_{max}$=0.1 g only few differencies can be noted between the ones obtained from the recorded time histories (Fig.1.a and 2.a) and the other ones from the simulation procedure (Fig. 1.b and 2.b). Infact the mean and the standard deviation (s.d.) are quite similar but the spectra from simulated accelerograms do not seem able to give a good characterization of the site seismicity. This fact can be pointed out especially when the values of the parameters to be used in the stochastic model have large differencies. Watching now to the normalized response spectra (Fig. 3.a/4.b) some differencies can be noted for the mean spectra and the corresponding s.d.. These discrepancies appear to be evident mainly in the range of low frequencies because of the amplification induced by the normalizing technique respect to the higher frequencies inside the same range of normalization. Also in these figures can be observed that the simulation is not able to give accurate interpretations about the site seismicity. The response spectra obtained from the simulated accelerograms seem to behave in similar way and have a trend to be more smoothed if compared with the ones obtained from the digitized records. Probably the above observed discrepancies should be less significant for higher values of the damping coefficients.

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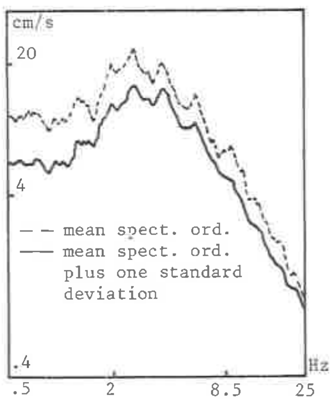

Fig.1.a - Spectral ordinates from recorded accelerograms normalized in acceleration relevant to Tolmezzo.

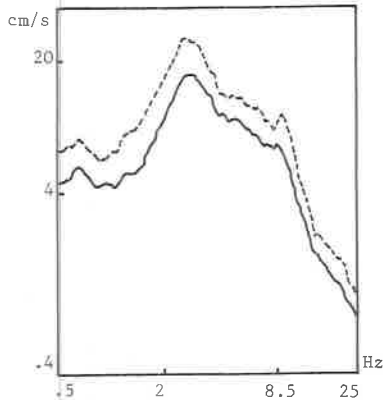

Fig.2.a - Spectral ordinates from recorded acc. normalized in acc. relevant to Forgaria-Cornino.

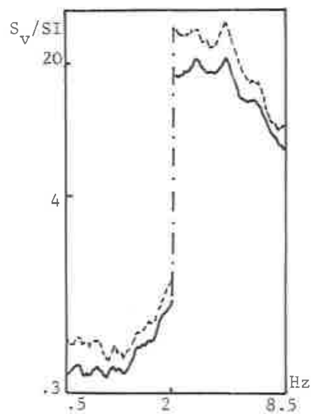

Fig.3.a - Spectral ordinates from recorded acc. normalized in SI relevant to Tolmezzo.

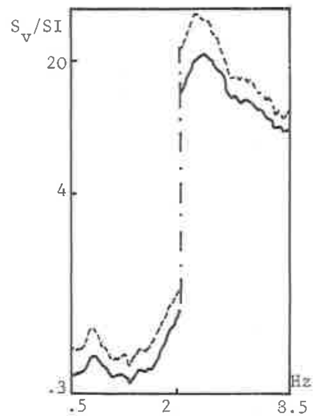

Fig.4.a-Spectral ordinates from recorded acc.normalized in SI relevant to Forgaria Cornino.

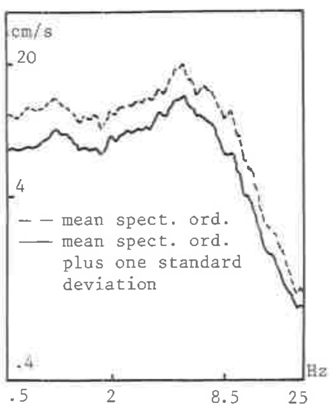

Fig.1.b - Spectral ordinates from simulated acc.(G_o=1),correlated and normalized in acc. (Tolmezzo)

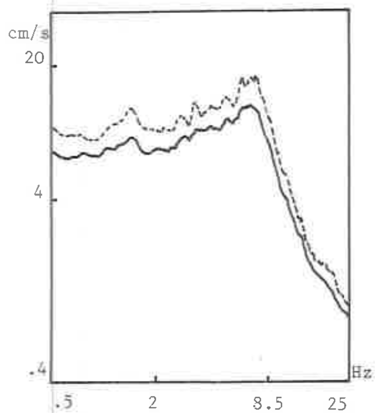

Fig.2.b - Spectral ordinates from simulated acc.(G_o=1), correlated and normalized in acc.(Forg.- Cor.)

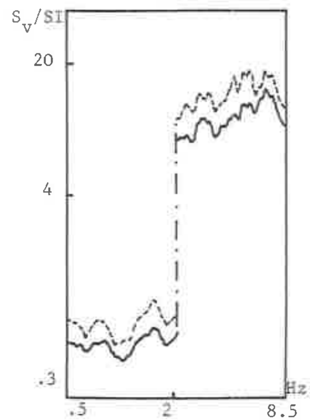

Fig.3.b-Spectral ordinates from sim. acc. (G_o sim.) corr. and norm. in SI (Tolmezzo).

Fig.4.b-Spectral ordinates from sim. acc.(G_o sim.) corr. and norm. in SI(Forg.-Cor.)