Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

High-reliability aseismic design

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ABSTRACT: The paper reports about further developments of the technique, presented in previous papers by one of the authors (Baratta (1979),(1980),(1981)), to produce the maximum theoretical values of the structural response under seismic load at a given site. The goal is pursued combining available techniques for the synthesis of random accelerograms (Ruiz Penzien (1971)) with the optimization procedures capable to maximize some parameters, significant for aseismic design, in the respect of the constraints represented by the basic values characteristic of the shaking properties at the site. Some of those values have been determined by probabilistic models (Baratta (1985), Zuccaro (1986)) for hazard assessment, as the seismic occurrence rate at the site, some by calibration of the filter constants to shape the accelerograms generated alike the local registrations. Eventually the spectra of the possible maximum response of the structures in Naples town (Italy) is built; the values are compared with the spectral response obtained by the records reported at stations around Naples during the 1980 earthquake in Irpinia region.

1. INTRODUCTION

The safety of the structures in seismic areas is highly connected to the calibration of the appropriate seismic loads to be introduced in structural analysis. Certainly this is one of the most interesting subjects of the seismic engineering. The extreme variability of the fundamental parameters describing an earthquake at a given site, does not allow to define the solution of the problem by deterministic methods, while the intrinsic nature of the phenomenon suggests the probabilistic approach. Moreover the lack of instrumental registrations for events of significant magnitude has lead the researchers to generate a sufficient number of synthetic earthquakes reproducing the fundamental characteristics of the seismic events at the site. In fact it has been observed, all over the world, that some properties of the registered accelerograms (peak acceleration, duration, decay constant, etc.) are strictly related to the localization of the epicenter. Therefore a large part of the seismic generator algorithms depend on a large number of random parameters correlated to the accelerograms coordinates plus a finite number of local characteristics which represent the constants conditioning the properties of the accelerograms to be generated.

2. ALGORITHM

Let $\underline{x}$ be the sample of realizations of a random variables x_i (i=1, ...n) and $\underline{l}$ the assigned local characteristics reflecting the statistics of the accelerograms at the site: the component $R(\underline{x};\underline{l})$ of the structure response can be evaluated by iterated sampling of the random variables $\underline{x}$ in a very large range (n=1000). Moreover if μ_x and $\sigma_x{}^2$ are the expected value and variance, respectively

$$\sum_{i=1}^{n} x_i = n\mu_x \tag{1}$$

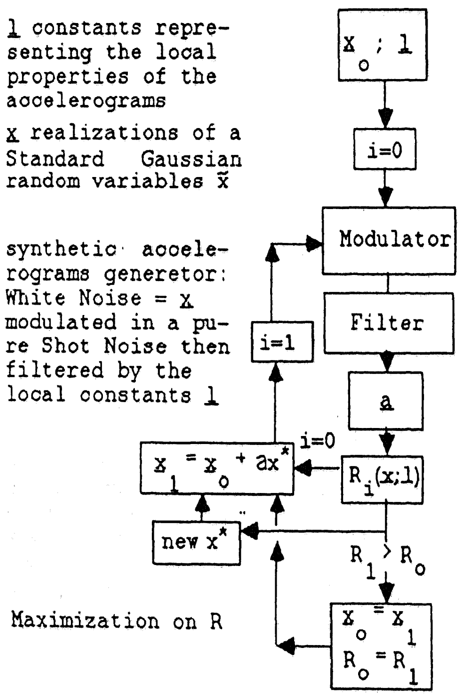
$$\sum_{i=1}^{n} x_i = (x_i - \mu_x)^2 = n\sigma_x^2 \tag{2}$$

$$n(a,b) = n[P(b) - P(a)] \ \forall \ (a,b) \in \underline{x}^2 \tag{3}$$

where $n(a,b)$ is the number of components of x falling in the interval (a,b), and X is the range of the values of x_i $(i=1, \ldots .n)$. The problem turns into the maximization of the function

$$R^*(x;l) = \sup_x R(x;l) \qquad (4)$$

where (1), (2) and (3) play the role of constraints on x which has been assumed, to simplify the operative procedure, as a Random Standard Gaussian variable (RSG), $(\mu_x=0 ; \sigma_x^2=1)$.
The optimization has been conducted by random-search procedures that verify the above constraints almost spontaneously (see Rao (1978)); alike the classical maximization methods which turn out to be inadequated for the constraints described.
Eventually the guided simulation procedure can be better understood looking the following flow-chart.



where x^* is a Standard Gaussian realization of the variables x and $\alpha \in [0,1]$.
One observes that x is RSG having been generated by x_o and x^* both RSG with independent components.
The simulation model adopted is the one reported by Ruiz and Penzien (1971).

The method assumes the seismic event to be a non-stationary stochastic process, the artificial earthquakes are generated by a Shot Noise (SN) obtained by modulating a white noise (WN) process with a function of time $\phi(t)$ then filtered through a second order linear system with damping ratio and an undamped circular frequency (see Ruiz-Penzien, 1971 for details).

3. CALIBRATION OF THE LOCAL CONSTANTS

The local components are:

ω_o	the pulsation
ξ	the damping ratio
t_i, t_o, c	parameters of $\phi(t)$
a_o	expected peak acceleration
T_o	duration of the event

ω_o and ξ have been determined by fitting the Kanai - Tajimi function to the average power equation of eathquakes recorded during the 23th of november 1980 event at stations around Naples area.
The duration of parabolic build up t_i and the time at beginning of decay t_o are determined by inspection of the variance intensity function $\phi(t)$ obtained from the data available, while the decay constant c is get by optimizing, by the least squares method, the values of $\phi(t)$, obtained from data, with the best fitting exponential curve for $t>t_o$. One observes that the limitation of instrumental records of earthquakes in neapolitan area produce a large variability of ϕ, however it estimates a satisfatoring smooth variance function, a better evaluation of ϕ will be possible once more sample records will be available.
Any fraction of gravity can be assumed as expected peak ground acceleration, just to compute the behaviour of the maximum response spectrum, this assumption will allow us to consider any value of a_o as factor of the spectral coordinates.
The duration of the event to be simulated has been assumed equal to the average duration in the area of the strong-motion phase. As a result, the constants assumed are:

$\omega_o = 16.34$ sec.$^{-1}$; $\xi = 0.66$

$t_i = 2$ sec. ; $t_o = 10$ sec.

$a_o = 0.1$ g ; $T_o = 17$ sec.

$c = 0.25$

4. NUMERICAL RESULTS

The maximum possible values of the acceleration response computed by the procedure proposed are plotted in fig. 1, and are compared to the average response obtained from 1980 data, both normalized to the same peak acceleration.
One assumes a damping ratio of the single degree of freedom system equal to 5%.

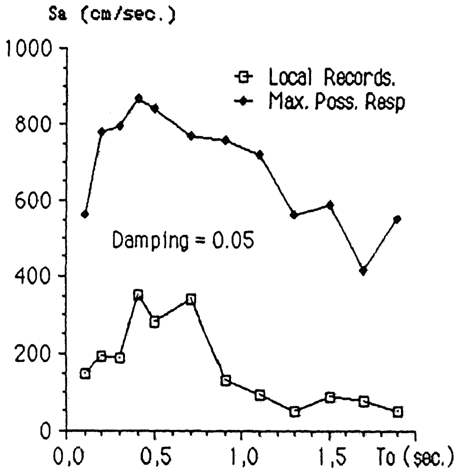


Figure 1. Comparison between acceleration spectrum response from data and maximum possible ordinates.

5.HAHARD EVALUATION OF NAPLES SITE

The above analysis allows to reduce the uncertainty in checking safety, deriving from the accelerogram shape. In order to make the procedure effective, it is thus possible to leave only one uncertain parameter, the peak ground acceleration, that is approached by the following method.
The evaluation of seismic hazard has been performed by application of two distinct procedures: S.I.S.M.A. (Coburn,Spence, Zuccaro,(1986)) and SIM-SIS(Baratta,Cacace, (1985)).
The Seismic Impact Simulation Model for risk Assessment is based on a systematic approach following probabilistic theory (Cornell, 1968).
The model assumes that the hazard at a point derives from earthquakes generated in source zones which have uniform seismicity defined by a linear recurrence relationship (Gutenberg and Richter, 1954).
The locational hazard,expressed in terms of probability of exceedance of a particular parameter of ground motion (e.g. intensity or peak ground acceleration) is determined by the use of source to site attenuation relationships derived from past earthquake data. The pattern of arrival times, given an average recurrence rate, is assumed to follow the Poisson law.
The SIM-SIS is a Simulation Model of the Seismic History on the territory.
It is based on an arrival Poissonian process and on Gutenberg and Richter (1954) seismicity law. The territory is overlapped by a very fit grid, one assignes to each cell the probability of epicentral location as function of the magnitude. The attenuation law is isotropic with random perturbations,while the local amplification coefficient is derived by a procedure based on Ruiz-Penzien (1971) generator of synthetic accelerograms. The simulation starts assuming a prefixed window of time (e.g.100 years), and generating the arrivals time of the events and the relative magnitudes with independent statistics.
Then one localizes the epicenter following the correlation with the magnitude and eventually through propagation and amplification procedures the effects at the site are determined.
The results obtained by the application of both the models have proved to be essentially coincident.This circumstance encourages the authors to further investigate in this direction in the future.

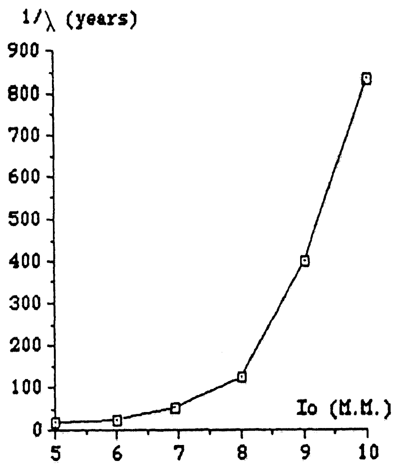


Figure 2. Correlation epicentral intensity (M.M) against Return Period, both models.

6. PEAK GROUND ACCELERATION - INTENSITY - RETURN PERIOD CORRELATIONS

To estimate the most probable Peak Ground Acceleration (PGA) at the site one needs to correlate the damage measure Io to PGA recorded in the past earthquakes or, alternatively, one can assume the Richter correlation:

$$\text{Log } a_p = \frac{I_o}{3} - \frac{1}{2}$$

(5)

Studies on the correlation between PGA and intensity, aiming at finding a dimensionless measure of the damage at a given level of shaking at ground (Coburn-Sakai-Spence-Pomonis, 1990), show that the correlation proposed by Margottini (see Coburn & others (1990) for details), based on 1980 earthquake data, is the most comparable tó the best fitting of several set of damage data from sites all over the world. The PGA-intensity correlation assumed (Coburn & others, 1990) is:

$$\text{LogPGA} = 1.84 + 0.057\psi$$

(6)

where ψ is a parameter correlated to the intensity.

table 1. correspondence between ψ (M.M.) intensity scale.

ψ	-1	2	7.5	10	13	16
I(M.M.)	V	VI	VII	VIII	IX	X

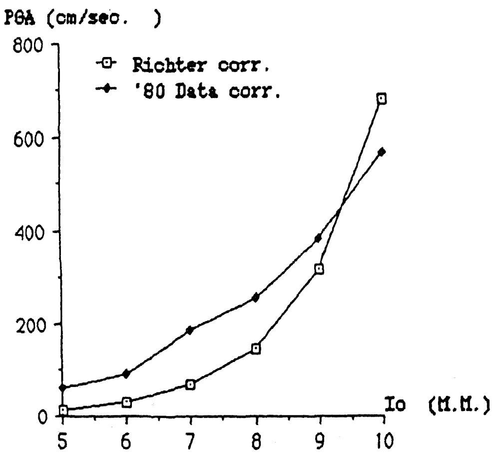


Figure 3. PGA-intensity correlations

One observes that the Margottini correlation is more realistic for Naples area; this is shown in fig. 4 where the correspondence PGA-Return Period for both the correlations proposed has been plotted.

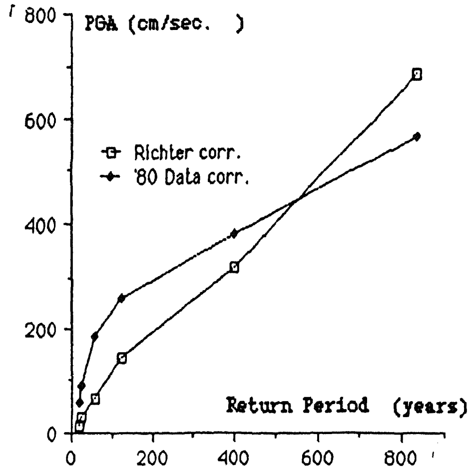


Figure 4. Return Period-PGA relations

7. STRUCTURAL RESPONSE AT NAPLES SITE FOR ASSIGNED RETURN PERIOD DESIGN

One chooses the return periods of 25, 50, 100, 500 years, the correspondent PGA are read by graph of fig.4. The acceleration spectral response is compute by the following relation:

$$S_{a_i} = \frac{a_{p_i}}{a_o} * S_{a_{max}} \quad (7)$$

where i=(25,50,100,500 yrs.), a_o=0.1 g and Sa_{max} the maximum response shown in fig.1. The values of accelerations plotted in fig. 5 have been expressed in percentage of gravity.

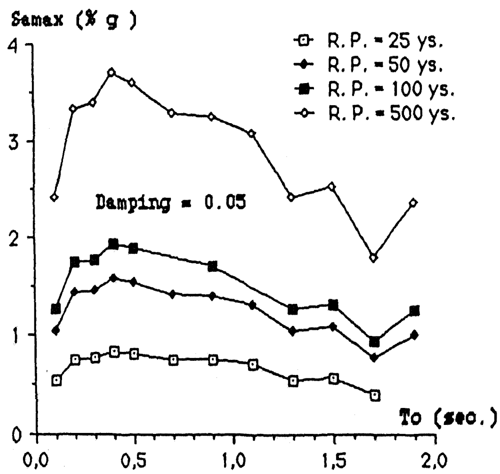


Figure 5. Maximum acceleration responses for some return periods design in Naples area.

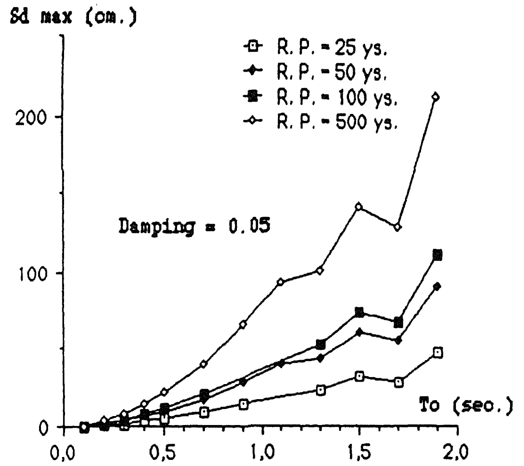


Figure 6. Maximum displacement responses for some return periods design in Naples area.

The maximum displacement spectral response is directly derived from values of fig.5.

8. CONCLUSIONS

The aim of the present study is to eliminate the seismic uncertainty and to reconduct the safety computation to a mono-parametric analysis (Drenick,(1973); Baratta,(1979); Corsanego,(1990)).

Therefore the procedure reported is proposed as a possible approach in high-reliability aseismic design (hrad).

In the paper one has investigated the worst response a single degree of freedom system can perform under a given shaking load. In other words one has studied the worst possible effect on the structure produced by an earthquake of a given intensity.

Considering the results obtained, the maximum possible values of the structural response seem to be plausible for operative purposes. In fact if one considers the PGA and the maximum value of the spectral acceleration response obtained by the 1980 earthquake set of data, the amplification factor $AF=S_a/a_p$ is 2.5 times minor than the AF one gets by the maximum possible values of the acceleration response of the structure. This result can be considered acceptable if one takes into account that the the response estimated is the maximum possible.

One observes that beginning from the maximum possible values of the response reported above, any reduction philosophy is adoptable to define the acceleration to assume for hrad. The acceleration values plotted in fig.5 have been computed within the elastic phase, therefore the introduction of a ductility coefficient (e.g. δ = 4) could, for example, be taken in consideration.

Of course the choice to introduce any reduction factor depend on the expense percentage the community should be ready to pay to adopt hrad to structures of particular interest. Cost-benefit analysis on this subject (Zuccarq,1991) shown that for structures with t_o > 1.5 sec. (e.g. steel frame) the hrad is not prohibitive, while for the structures with t_o < 1.5 sec. (e.g. reinforced concrete frame) the adoption of special aseismic structural type is need.

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