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THE ROLE OF UNCERTAINTIES IN THE EVALUATION OF LOCAL SEISMIC RISK

Sergio LAGOMARSINO[1], Giovanni SOLARI[1] and Dino STURA[1]

[1]Institute of Structural Engineering, University of Genoa, Genoa, Italy

SUMMARY

This paper applies the response surface method in order to determine the role of uncertainties in the evaluation of the local seismic risk. On the basis of this formulation soil amplification is studied from a probabilistic point of view. The analysis furnishes both a stochastic interpretation of the randomness of the solution and the contribution of the single stochastic variables to the global uncertainty.

INTRODUCTION

In seismic microzoning analyses at both small or large scale it is essential the joined contribution of experts of several and different fields such as geophysics, geotechnique, geodynamics and engineering. A correct study of hazard must in fact consider the following factors: (1) the earthquake occurence pattern; (2) the source mechanism; (3) the wave propagation path; (4) the local soil conditions. Everyone of these subjects is equally important and it is therefore fundamental, if such a study is to be successfully concluded, to carry out the analysis homogenously.

The characteristics of the first three arguments make it necessary to deal with these problems adopting probabilistic methodologies. The results arrived at are often represented by peak accelerations or, even better, by response spectra with different probability levels.

The fourth problem concerns the effects of local soil conditions and the related modifications that the seismic waves undergo in the last 100-200 meters before reaching the ground surface. The phenomenon, well known as local amplification, is affected both by the morphological characteristics of the site and also by the geomechanical properties of the ground. The analysis of the state of damage in sites that have suffered a destructive earthquake has often revealed different behaviour of similar constructions clearly due to soil amplification.

Under this point of view the local soil conditions represent the last but not least element to be considered during the studies of seismic microzoning. Actually, to evaluate amplification correctly, it is necessary to have instruments which if, on the one hand, have to be general and easily used to give indications on a rather wide scale, on the other hand must deal with the problem from a probabilistic viewpoint both because of the typically stochastic nature of the parameters concerned and because of the direction taken by the preceeding steps in the investigation of hazard.

In this context the formulations that fase this problem by probabilistically characterizing the seismic motion have been in the literature for quite some times, while those that extend the statistical vision to the ground parameters seem to be still rarely used. This fact is surprising since everyone knows the primary role played by the uncertainties characterizing these parameters. Christian affirms that "the uncertainty in the material properties and model laws tends to mitigate the advantages of more sophisticated analyses that include detailed computation of effects of given earthquakes" (Ref.1).

It should however be observed that, due to the large number of uncertain quantities on which soil amplification depends, the classical procedures treating the propagation of uncertaities by means of convolution integrals, perturbation methods and Monte Carlo simulation techniques are usually too burdensome and therefore inadequate for this purpose. Furthermore there is a basic limit which all these procedures have in common, namely, that they give the randomness of the solution but does not contain informations about the contribution of the single stochastic variables to the global uncertainty.

In the light of these considerations this paper proposes a two-steps general methodology for evaluating the local seismic risk taking into account the uncertainties of soil parameters. In the first step the problem of soil amplification is formulated and some or all parameters on which it depends are stochastically characterized. In the second step the problem is solved by the response surface technique (Ref.2); this method, which in the past has been used with success in several fields (chemistry, biology, geology, ...), only recently has been adopted in the engineering sector (Ref.3).

This study is part of a wider and more general research activity in which the authors are at present preparing some more extensive and exhaustive reports.

FORMULATION OF THE PROBLEM AND STOCHASTIC CHARACTERIZATION OF THE PARAMETERS

Let us consider a soil deposit resting on an elastic bedrock and denote by B a generic quantity (a peak acceleration, a time-history, a response spectrum, a power spectral density,...) representing the seismic input motion assigned at the bedrock or at an outcropping; B is the result of phases (1), (2) and (3) of the microzoning analysis. The corresponding quantity representing the seismic output motion at the free-field can be defined as F=TB, in which T is an operator depending on the properties of the deposit and, in the hypothesis of non-linear soil behaviour, on the input seismic motion too. From a general point of view the evaluation of T, and therefore of F, calls for the application of finite element techniques to bi- or three-dimensional models.

This study can be substantially simplified when considering a horizontally stratified deposit subjected to vertical P- and S-seismic waves. In the hypothesis of linear soil behaviour, T is a function of the thickness H_k, of the mass per unit volume ρ_k, of the shear modulus G_k and of the damping ratio D_k of each k-th soil layer; furthermore it depends on the mass per unit volume ρ_b, on the shear modulus G_b and on the damping ratio D_b of the elastic bedrock (Ref.4). When soil non-linearity is taken into consideration, G_k and D_k are also functions of the soil strain and, therefore, of the seismic input B. If X denotes the set of the n variables x_i (i=1,...n) on which the problem depends, then F can be formally expressed as:

$$F(X) = F(x_1,x_2,\ldots x_n) \tag{1}$$

The classical formulations of local seismic risk treat X as deterministic but, in reality, it possesses probabilistic properties. For this reason it should be represented through its joint probability distribution function

$p(X)=p(x_1,x_2,\ldots x_n)$. Among other relevant properties, the response surface method can be applied by describing X through only the array of the mean values $E(x_i)$ and of the standard deviations $S(x_i)$ $(i=1,\ldots n)$.

THE RESPONSE SURFACE METHOD

The response surface method is conveniently formulated by introducing a new set $\hat{X}$ of coded variables $\hat{x}_i=(x_i-E(x_i))/S(x_i)$ $(i=1,\ldots n)$. It consists of three sequential steps.

The first step is represented by the sensitivity analysis of the problem to the set $\hat{X}$ of the n stochastic variables $\hat{x}_i$ $(i=1,\ldots n)$ on which it depends. The analysis is performed by carrying out a series of 2n+1 deterministic evaluations of F. In the first one F is calculated assuming $\hat{x}_i=0$ $(i=1,\ldots n)$; in the others F is determined by setting $\hat{x}_i=0$ $(i=1,\ldots n;i\neq j)$ and $\hat{x}_j=\pm 1$. The results so obtained allow one to understand the relative importance of treating as stochastic each parameter. In this way it is possible to separate the initial set $\hat{X}$ of n random variables into a subset $\hat{Y}$ of m ($\leq$n) fundamental random variables and a subset $\hat{Z}$ of (n-m) secondary random varaiables which can be assumed as deterministic.

In the second step of the analysis F is approximated by a polynomial G, the response surface, around a point $P=(\bar{y}_1,\bar{y}_2,\ldots\bar{y}_m)$ (usually $\bar{y}_i=0$, $i=1,\ldots m$) in the space $\hat{Y}$ of the fundamental random variables $(\hat{y}_1,\hat{y}_2,\ldots\hat{y}_m)$:

$$G(\hat{Y},A) = a_o + \sum_{1}^{m}{}_i a_i\hat{y}_i + \sum_{1}^{m}{}_i\sum_{1}^{m}{}_j a_{ij}\hat{y}_i\hat{y}_j + \ldots \tag{2}$$

Not knowing the analytical expression of F, the only hypothesis requested to determine G is that F is smooth around P. The degree of the polynomial G is established on the basis of the results of the sensitivity analysis, while the set A of coefficients is obtained by means of a regression technique. Data needed at this purpose are calculated by means of a series of N deterministic analyses carried out by selecting appropriate combinations of the input parameters, according to the rules of the factorial design ($N=2^n$ if G is a hyperplane). In this context, adopting proper techniques, it is also possible to recover the actual randomness of the parameters defined as deterministic during the first step. The results of this method must be finally subjected to suitable significance tests that can highlight the opportunity of modifying the initial expression of G; in this case an iterative solution can be established.

In the third and last step of the study the response surface is used for quantifying the uncertainties affecting the results. This operation can be limited to the determination of the mean value and of the coefficient of variation of F. As an alternative it can be developed up to the estimation of the crossing probability of any given threshold; this result can be obtained by using suitable methods such as the FOSM (First-Order Second-Moment) technique.

In conclusion it is essential to observe that the procedure stated above gives both a stochastic interpretation of the randomness of the solution, and some general indications about the contribution of each stochastic variable to the global uncertainty.

NUMERICAL EXAMPLE

The application of the response surface method is herein illustrated with reference to four scenarios representative of standard layering (Ref.5). The first one (I) is a rock site, the second (IIa) and the third (IIb) are deposits of intermediate thickness, the fourth (III) is a thick stratum. The local seismic risk is evaluated by analyzing the monodimensional amplification of three horizontal homogeneous visco-elastic soil layers (IIa,IIb,III) resting on a flexible bedrock (I) and subjected to vertical seismic shear waves. Soil parameters are treated as a set $X=(H,V,V_b,D,D_b)$ ($V=\sqrt{G/\rho}$) of 5 random normal variables the properties of which are summarized in Table 1 ($C(X)=S(X)/E(X)$; $V=V_b$, $D=D_b$ for Class I). The input seismic motion (Fig.1), treated as a deterministic quantity, is applied at the outcropping of the elastic bedrock (I). All calculations are executed by means of computer program SHAKE (Ref.6). The result of the analysis is herein represented by the ratio F_a between the peak accelerations a_f and a_o at the free-field and at the outcropping, respectively.

	CLASS I		CLASS IIa		CLASS IIb		CLASS III	
X	E(X)	C(X)	E(X)	C(X)	E(X)	C(X)	E(X)	C(X)
H (m)	∞	-	15.	.30	37.	.40	200.	.40
V (m/s)	1890.	.40	450.	.40	475.	.40	650.	.26
D (%)	1.5	.60	7.	.60	7.	.60	7.	.60

Table 1 Soil properties of scenarios selected as test case

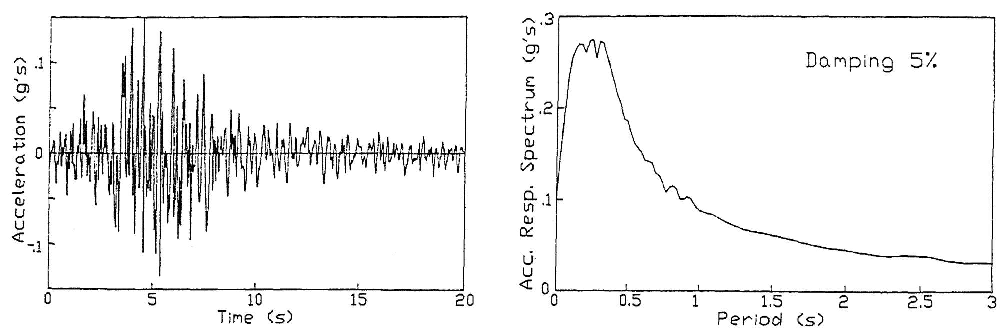


Fig. 1 Seismic input motion

Fig.2 shows the results of the sensitivity analysis in terms of the coded variables $\hat{X}$. It is apparent that the uncertainty of D_b does not affect F_a; for

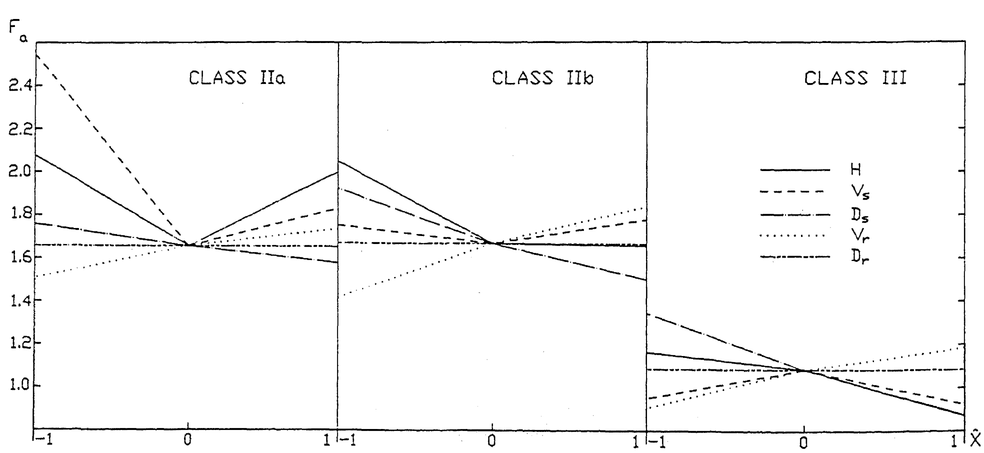


Fig. 2 Sensitivity analysis

this reason the response surface G is built in the space $\hat{Y}$ of the 4 fundamental random variables $(\hat{H},\hat{V},\hat{V}_b,\hat{D})$, while D_b=1.5% is treated as a deterministic quantity. Fig.2 also shows that F_a is an almost linear function of $\hat{D}$ and $\hat{V}_b$, while its dependence on $\hat{H}$ and $\hat{V}$ is better represented by a quadratic form. These considerations are common to all case studies and lead to the following expression of G:

$$G = a_o + a_1\hat{H} + a_2\hat{V} + a_3\hat{V}_b + a_4\hat{D} + a_{11}\hat{H}^2 + a_{22}\hat{V}^2 + a_{12}\hat{H}\hat{V} \tag{3}$$

Table 2 shows the sequence of the N=21 values of $\hat{Y}$ with reference to which F_a is calculated. Table 3 summarizes the set of coefficients determined by means of a regression to the least squares. Figs.3 shows some diagrams of the related response surfaces. Table 4 finally reports the mean value and the coefficient of variation of F_a.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
H	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	$-\sqrt{2}$	$\sqrt{2}$	0	0	0
V	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	0	0	$-\sqrt{2}$	$\sqrt{2}$	0
V_r	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	0	0	0	0	0
D	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	0	0	0	0	0

Table 2 Sequence of selected values of $\hat{Y}$

	a_0	a_1	a_2	a_3	a_4	a_{11}	a_{22}	a_{12}
IIa	1.6550	-.0830	-.2304	.2260	-.2477	.1715	.0958	-.0374
IIb	1.6670	-.1044	-.1237	.2214	-.2689	-.0341	-.0114	.1033
III	1.0850	-.1017	.0215	.1544	-.2484	-.0091	-.0645	.0375

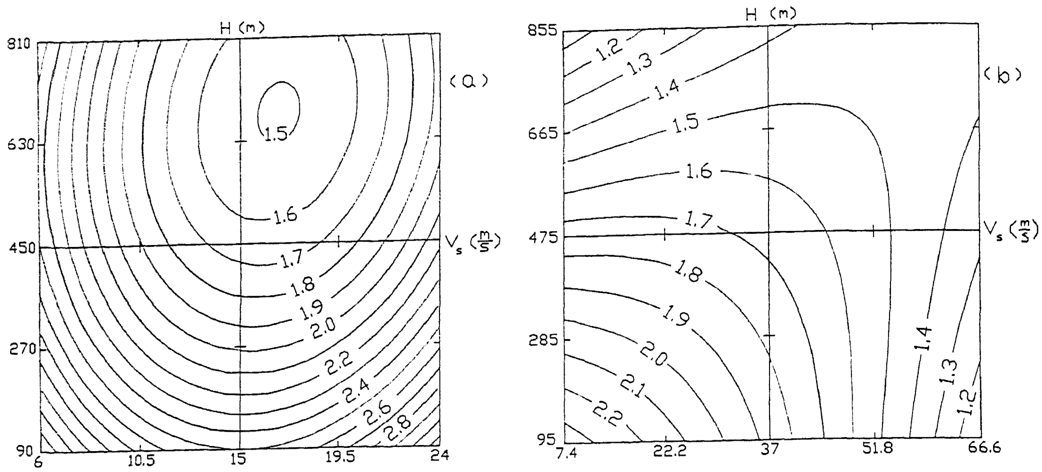
Table 3 Final results of the analysis

	CLASS IIa	CLASS IIb	CLASS III
$E(F_a)$	1.92232	1.62147	1.01139
$C(F_a)$	0.27569	0.28188	0.39397

Table 4 Mean and coefficient of variation of response

CONCLUSIONS

This paper applies the response surface method for evaluating the local seismic risk taking into account the role of uncertainties. This procedure gives rise to extremely meaningful and suitable results, especially when applied to problems governed by a limited number of stochastic variables. Under this point of view the response surface method is particularly profitable for analyses of monodimensional amplification. On the other hand, when problems of bi- and three-dimensional amplification are concerned, this technique loses much of its efficacy. In these cases the propagation of uncertainties can be better evaluated through the stochastic finite element technique (Ref.7). This, at the present state of the art, seems however to be too burdensome especially when applied to the dynamic analysis of very large systems.



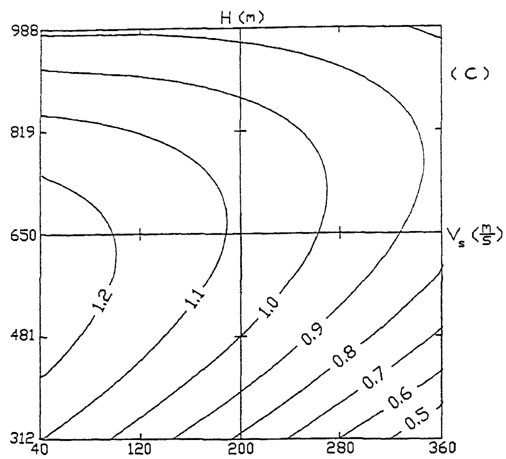


Fig. 3 Response surfaces as functions of $\hat{H}$ and $\hat{V}$

(a) Class IIa - V_b=450m/s D=7%

(b) Class IIb - V_b=475m/s D=7%

(c) Class III - V_b=650m/s D=7%

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