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CONCEPTUAL FRAMEWORK FOR A FULL SPECIFICATION OF SITE CONDITIONS

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SUMMARY

A consistent approach to dynamic analysis and risk estimates is looked for in relation to methods and data used. Alternative representations of ground motion and relationships between them are discussed. A probabilistic representation of seismic hazard considers several classes of possible ground motions. Probabilistic approaches of levels one and three are alternatively considered for risk analysis. Some consequences for the use of artificial accelerograms are derived, keeping in view the criteria of linearity, goals of analysis, level of probabilistic approach and sites dealt with. Some summary recommendations are finally derived.

1.INTRODUCTION

Earthquake resistant design must rely in principle on consistent estimates of risk or, conversely, of safety. A significant and realistic specification of seismic site conditions is an essential prerequisite for the goal of conducting risk analyses. The specification of seismic conditions represents in some way a prediction of events to affect in future sites dealt with and this prediction can be performed, according to current knowledge, only in probabilistic terms.

The specification of seismic conditions must deal with two complementary aspects of seismicity : features of seismic motions as related to individual events (A') and features of the sequence of seismic events during a long period of time, to be comparable with the lifetime of structures (A"). An appropriate way of specifying seismic conditions must be conceived also in a way to be compatible with the philosophy of analyzing risk, or safety. One can consider alternatively three levels of probabilistic approach to structural safety analysis:P_1 (level one) or semi-probabilistic, P_2 (level two) or simplified probabilistic, P_3 (level three) or consistent probabilistic.

The goal of the paper is to contribute to the development of a more consistent philosophy in specifying site conditions. The approach starts basically from higher level tools, used in order to derive data to be compatible with engineering practice. The aspects successively discussed are concerning alternative representations of future ground motions and of seismicity, use of level one and level three probabilistic approaches in risk analysis, and consequences for the use of artificial accelerograms.

2. MODELS OF INDIVIDUAL MOTIONS

Further developments are specific for elevated structures, where the input is represented by a vector $W_g(t)$ of acceleration along the D'sOF of ground-structure interface and the output is represented by a vector $W_e(t)$ of acceleration along the D'sOF of the elevated part. The approach can be extended nevertheless to buried structures, dams interacting with reservoir water etc.

The specification of seismic conditions must ultimately provide adequate information on vectors $W_g(t)$ for any type of structure dealt with and this involves adoption of a representation connected with the aspect A'. One can deal at present with three basic representations in this relation: R_1' - stochastic representation, considering $W_g(t)$ a random function of time; R_2' - system of (artificially generated) sample vectors $W_g(t)$; R_3' - design spectra. Any of them can be used for predictive purposes, yet it is useful to analyze some interrelations of them.

The use of R_1' means in practice the use of covariance matrices and of classical or generalized spectrum density matrices. The canonic expansion (Ref.1) of non-stationary vectors,

$$W_g(t) = \sum_s a_s(t)\, W_s(t) \qquad (2.1)$$

($a_s(t)$:deterministic envelopes; $W_s(t)$:stationary, not cross-coreleted random vectors) is of fundamental interest from analytical and computational viewpoints both This expansion may be given an interesting physical sense:its terms may correspond to the various phases of seismic waves (P- waves, S- waves etc.).

The R_2' approach can be conveniently discussed in connection with a widely used algorithm of generating systems of sample artificial accelerograms. The components $w_{sk}(t)$ of vectors $W_s(t)$ (2.1) may be expressed as

$$w_{sk}(t) = \Sigma_b w^{(o)}_{skb} \ \exp(i\ \omega_b t + \phi_{skb}) \qquad (\ \omega_{b+1} - \omega_b = \Delta\omega = \text{ct.}) \qquad (2.2)$$

One approach to account for the coherence characteristics as defined by a classical spectrum density matrix of $W_s(t)$, $S^{(s)}\{W_s;\ \omega_m\}$ ($\omega_m = (\ \omega_1 + \omega_2)/2$ as used in the representation adopted in (Ref.2) for generalized spectrum densities, (Ref.3)) is to derive appropriate linear combinations of the components $w_{sk}(t)$ for which random initial phases were initially generated. This way was at the basis of one of the models used in (Ref.4) in order to generate vectorial artificial accelerograms . The use of R_2' makes it possible to reflect the same features of individual (vectorial) ground motions as R_1' and systems of sample vectors $W_g(t)$ can be directly derived from data on spectrum density matrices . One major advantage of it consists of the easy usability in non-linear analyses, where the R_1' approach is difficult. Deriving R_1' characteristics from R_2' characteristics raises difficult identification problems.

The R_3' approach can account for individual components $w_{gk}(t)$ only , without regard to cross-correlation or coherence characteristics. R_3' data can be derived from either of R_1' or R_2' bases, as design spectra with controlled (conditional) non-exceedance probabilities. An R_1' startpoint will use parametrized transfer functions and estimates based on distributions of values of output accelerations while an R_2' startpoint will use a Monte-Carlo approach (suitably based on FFT, to avoid time-history integration) and statistical analysis of output for sample accelerograms. In order to provide consistency to the R_3' approach, after accepting its philosophy, it is necessary to carry out convolutions with hazard characteristics, as discussed in section 3, eliminating the conditional character of exceedance probabilities considered. The opposite way, i.e. passing from R_3' to R_1' or to R_2' has only approximate solutions that may considerably depend on models adopted. Moreover, information on cross-correlations etc. is fundamentally absent in R_3' data. R_3' is rediscussed in section 4 in connection with risk analysis.

It will be assumed, in relation to further developments, that any kind of model is characterized by a finite system of parameters, denoted q_a or Q (vector). The parameters q_a could be related for instance : in case of R_1', to predominant frequencies and selectivity characteristics of spectrum densities of components $w_{sk}(t)$, to time moments and amplitudes characterizing the envelopes $a_s(t)$ (2.1) etc.; in case of R_3', to some corner frequencies and corresponding ordinates of (smoothed) design spectra. This discretization is essential in order to develop algorithms compatible with automated analyses.

3. MODELS OF GROUND MOTION IN CONNECTION WITH MODELS OF SEISMICITY

The seismic hazard of a definite site is characterized by the random occurrence of ground motions with different characteristics (intensity, PGA, EPA, corner frequency, predominant frequency etc.). The possible values of parameters q_a will define domains Ω for the vectors Q. In order to obtain practically usable relationships it will be assumed that all possible systems of values q_a can be lumped into a finite system of classes (j) of motions, such that motions pertaining to a definite class differ only by the value of one amplitude-of-motion type parameter, q.A definition based on EPA and EPV (Ref.5)

$$q = \{EPA.EPV\}^{1/2} \qquad (3.1)$$

is proposed, given the good correlation of log q with macroseismic intensity (Ref. 6). One can consider here also the corner circular frequency ω_c,

$$\omega_c = EPA/EPV\ , \qquad (3.2)$$

which can be discretized into values ω_{cj} defining in a simplest way different classes (j) of motions.

The simplest model used to characterize seismicity, which is used here too, is poissonian (representation R_1''). More complex models (markovian, renewal process), (Ref.7), referred to as representation R_2'', require for calibration data more difficult to obtain. The basic R_1'' characteristic of site seismicity is the expected number of cases of exceedance of amplitude q, by motions of a class (j), during a lifetime T (years), denoted $\bar{N}_j^{(h)}(q,T)$, which has a structure

$$\bar{N}_j^{(h)}(q,T) = T \int_q^\infty \bar{n}_j^{(h)}(q')\ dq' \qquad (3.3)$$

($\bar{n}_j^{(h)}(q)$:density of frequency of occurrence for unit time interval). One can derive on this basis return periods $\bar{T}_j^{(h)}(q)$,

$$\bar{T}_j^{(h)}(q) = \{ \int_q^\infty \bar{n}_j^{(h)}(q')\ dq' \}^{-1} \qquad (3.4)$$

(the superscript (h) stands here for seismic hazard). The function $\bar{N}_j^{(h)}(q,T)$ is the argument of a Poisson distribution $G_{jm}^{(h)}(q,T)$ related to m cases of occurrence of motions of class (j), exceeding q, in T years,

$$G_{jm}^{(h)} = \frac{\{\bar{N}^{(h)}(q,T)\}^m}{m!} \exp\{-\bar{N}^{(h)}(q,T)\} \qquad (3.5)$$

Design spectra with controlled non-exceedance probability over a definite structural lifetime, pertaining to R_3', can be derived using an R_1'' approach. Consider a design spectrum for absolute acceleration $s^{(aa)}(f,n)$ (f:oscillation frequency;n:fraction of critical damping). Conditional exceedance probabilities $p_j^{(s)}(f,n,;q)$ by actual spectra of motions pertaining to classes (j), with amplitude q, can be primarily derived. The overall number of cases of exceedance $\bar{N}^{(s)}(f,n;T)$, can be derived by means of a convolution

$$\bar{N}^{(s)}(f,n;T) = T \sum_j \int_o^\infty p_j^{(s)}(f,n;q)\bar{n}_j^{(h)}(q)\ dq \qquad (3.6)$$

A corresponding Poisson distribution, homologous to (3.5), can be derived using $\bar{N}^{(s)}(f,n;T)$ as an argument.

Note here that it is not possible to use a similar way in case of an R'_1 or R'_2 approach. That is due, primarily, to the multi-parameter nature of R'_1 and R'_2, which makes it difficult to introduce order relations. As a consequence, there will be different possibilities of using R'_1 or R'_2, versus R'_3, as emphasized further on.

4.RISK ANALYSIS

Reference was made in the introduction to the three levels, P_1, P_2 and P_3, of probabilistic approach to risk, or safety, analysis. Some further relations are based on a P_3 approach. The author considers the level P_2 not well suited for the case of recurrent actions like that due to seismicity. The level P_1 provides basically no overall risk or safety estimate, yet its practical importance cannot be denied, given the state of the art of design regulatory basis. The concepts of hazard, vulnerability, risk etc. are considered here in the same frame as in (Ref. 8).

The vulnerability of a structure to seismic action may be quantified in probabilistic terms and this quantification can be related to the alternative representations of seismic conditions, as dealt with in previous sections. In case one considers various limit states (1), the vulnerability of a structure can be characterized by a system of conditional probabilities, $F_{1j}^{(v)}(q)$, i.e. the probabilities of exceedance of limit states (1), conditional upon the occurrence of a ground motion of amplitude q, pertaining to a class of motions (j). The function $F_{1j}^{(v)}(q)$ may be at the basis of the definition of a resistance characteristic of a structure, expressed in terms of amplitude of motion, $q_{1j}^{(v)}(p)$, whereby p is an exceedance probability (e.g. $q_{1j}^{(v)}(p)$ may be a motion amplitude for class (j) leading to the exceedance of yield point with a probability p=0.2). The equation for $q_{1j}^{(v)}(p)$ is

$$F_{1j}^{(v)}\{q_{1j}^{(v)}(p)\} = p \tag{4.1}$$

The function $q_{1j}^{(v)}(p)$ is a structural resistance characteristic that pertains basically to the P_1 philosophy. According to the current state of the art, this kind of characteristic is appropriate for seismic qualification of structures, equipment etc. One can use in this respect also a quantification in terms of return periods $\bar{T}_{1j}^{(v)}(p)$,

$$\bar{N}^{(h)}\ \{q_{1j}^{(v)}(p)\ ,\ \bar{T}_{1j}^{(v)}(p)\ \} = 1 \tag{4.2}$$

The parameters $\bar{T}_{1j}^{(v)}(p)$ will represent basically safety characteristics, since passing from a resistance characteristic $q_{1j}^{(v)}(p)$ to them implies consideration of hazard features quantified by return periods of various intensities or amplitudes.

The risk of exceedance of a limit state (1) will be characterized basically (P_3) by the expected member of cases of exceedance during a lifetime T, $\bar{N}_1^{(r)}(T)$. This function is given by a convolution

$$\bar{N}_1^{(r)}(T) = T\sum_j \int_o^\infty F_{1j}^{(v)}\ (q)\ \bar{n}_j^{(h)}(q)\ dq \tag{4.3}$$

The risk characteristic introduced makes sense under the implicit assumption that a structure affected by an earthquake is promptly and perfectly rehabilitated after the event. The acceptance of this implicit assumption makes it possible to extend the use of Poisson model from hazard to risk analysis. It will be possible to determine return periods of exceedance of limit states (1), $\bar{T}_1^{(r)}$, corresponding Poisson distributions etc.

A structural safety characteristic that fits rather to the P_1 philosophy may be of interest too. In case one considers the return periods $\bar{T}^{(v)}_{1j}(p)$ (4.2), the return period $\bar{T}^{(v)}_1(p)$ of intensities leading to exceedance of a limit state (1) with a probability p, (considering all classes (j) combined) will be

$$1 / \bar{T}^{(v)}_1(p) = \sum_j 1/ \bar{T}^{(v)}_{1j}(p) \qquad (4.4)$$

Note here some methodological extensions, to the case of multi-component built systems (Ref.8,9) and to the cases of multi-parameter performance criteria and of time-dependent masses or non-seismic loadings (Ref.10).

5.USE OF ARTIFICIAL ACCELEROGRAMS

The R'_3 limitations referred to lead to the necessity of implementing an R'_1 or R'_2 approach. Due to the difficulties of use in non-linear problems and to the lack of appropriate software, an R'_1 approach is confined at present rather to analytical research and development of models. The R'_2 approach, that makes it possible to overcome such difficulties, should be regarded therefore as a main way of development. Some remarks must be presented in this connection :

1. In case of linear analysis it is acceptable to use accelerograms defined on subspaces of the space of vectors $W_g(t)$ and to use appropriate linear superposition. In the non-linear case it will be necessary to use multi-dimensional accelerograms. Moreover, such analyses require as a rule to define multi-dimensional force-deflection relationships concerning the performance of structural components and to introduce corresponding criteria.

2. Another important condition is to define the goals of analysis. In case one puts emphasis primarily on qualitative aspects, the requirements will be less severe. In case one looks for quantitative results, it will be necessary to state whether they refer merely to the analysis of seismic resistance or to the analysis of seismic safety.

3. For structures for which the analyses are aimed to lead to safety estimates, it will be necessary to choose between P_1 and P_3 philosophies, and to consider the methodological implications illustrated by the developments of previous section. A P_3 philosophy will require parametric analyses for various q - values, in order to finally obtain risk or safety estimates by means of appropriate convolutions, like (4.3), while a P_1 philosophy can consider fixed values q, as related to some return periods or to some non-exceedance probabilities.

4. Finally, given a definite structural solution , there are differences between the one-site case and the multi-site case (repetitive structure). In the first case a P_3 approach will rely on specific hazard characteristics $\bar{N}^{(h)}_j(q,T)$, and (4.3) type convolutions can be performed. In the second case, unless one takes prospective sites one by one, calculations will be confined to vulnerability characteristics $\bar{F}^{(v)}_{1j}(p)$.

6. CONCLUDING REMARKS

1. A consistent analysis of seismic effects upon structures requires first a consistent system of data on ground motion. According to the current state of knowledge, it is necessary to develop in this connection stochastic models to fully account for the characteristics of vectors $W_g(t)$. Design spectra cannot account for more than one component of $W_g(t)$, taken separately. They should be considered as secondary characteristics of ground motions, to be derived on the basis of higher level data, like stochastic models or systems of sample artificial ac-

celerograms, derived at their turn from stochastic models.

2. Design spectra, when used, should be characterized by specified non-exceedance probabilities for definite structural lifetimes. Appropriate convolutions of exceedance probabilities of spectral values (conditional upon ground motion overall characteristics) and recurrence characteristics related to the seismicity of the site are due.The direct compatibility of design spectra with the semi-probabilistic approach to structural design must be noted.

3. Data and calculations in earthquake resistant analyses should be explicitely organized to lead to risk estimates. A consistent approach involves the adoption of a P_3 philosophy. Efforts should be made to further promote this approach, if not for any individual structure at present, at least as a background of code development, as well as in the design of repetitive (standardized)structures, for which in-depth analyses are highly justified.

4. The use of artificial accelerograms should be further on promoted, given its unique advantages. This approach should be consistent from the view point of safety analysis, fulfilling the specific requirements set for cases of non-linearity, by objectives of calculations, by the philosophy of safety verification adopted, by the number of sites considered. Research work required by this technique especially in relation to multi-dimensional,non-linear, non-holonomous force-deflection relationships, should be correspondingly supported.

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