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Non linear responses of simulated accelerograms

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ABSTRACT:The responses of elasto-plastic SDOF models in a wide range of natural periods for a large number of similar accelerograms have been calculated. These accelerograms were characterized by the same duration, the same maximum acceleration envelope and the same elastic response spectrum. The responses obtained using a small number of accelerograms have also been evaluated. The statistical comparison of the actual response distributions and of the estimated ones has led to the definition of an amplification factor of the estimated response. Using this factor it is possible to evaluate, for given estimate reliability levels, a "target" response that is the response characterized by a predesignate non-exceeding probability. The relation between the amplification factor and the solution reliability levels is shown, referring to the different numbers of accelerograms that are used in the response estimate.

1 INTRODUCTION

Structures characterized by a non-linear behaviour show a large scattering of the seismic response values with the varying of the input accelerograms. The response scattering is especially evident when time-histories recorded during actual earthquakes are used. On the other hand, accelerograms, also those recorded during the same earthquakes, strongly differ one from the other for frequency content, duration and maximum acceleration time-history.

Large non-linear response scatterings of structures are shown also when accelerograms artificially generated with homogeneity criteria are used.

The result scattering of the seismic analyses represents an obstacle to the diffusion of analysis methods based on step by step integration of the dynamic equilibrium equations in that it is necessary to repeat the analyses for a large number of accelerometric inputs to attain a statistically valid result. Since the dynamic direct solution is the only one practicable for structures with non linear behaviour, this obstacle restrains the use of non-linear modellings in structure analyses. Only with such modellings is it possible to evaluate those response quantities that are typical of elasto-plastic (EP) behaviours, for instance the ductility demanded to the plastic hinges of a ductile node frame or the maximum displacements of EP devices used in base isolation or energy dissipation systems.

In the present work a criterion to estimate an EP response value of a structure with a predeterminate reliability level is investigated, also using a limited number of accelerograms. The criterion is based on the statistic treatment of the results that are obtained using a large number of accelerograms.

2 CONTROL PARAMETERS OF THE EP RESPONSES

Previously developed researches (Mezzi & alt. 1990,1991) have shown how the spectrocompatible artificially generated accelerograms do not give rise to significant response scatterings when structural models with a linear elastic behaviour are considered. It is confirmed that the elastic structure response does not depend on the accelerogram "shape", but rather depends on its frequency contents. Therefore, in the elastic range, the earthquake elastic response spectrum is the parameter characterizing the seismic action intensity in relation to the produced response.

On the contrary, when the structure has a non-linear behaviour,and in particular an elasto-plastic behaviour, the response spectrum is no longer the representative parameter of the seismic intensity, that is of the response level. In fact, accelerograms characterized by the same response spectrum have given rise to large response scatterings during the simulations.

The response scattering in the EP range depends on the casual phase-difference between the energy inputs associated with the accelerogram pulses and the contemporary kinematic and mechanical state of the structure. The study of these interactions and that of the modality with which they are manifested is very complex. At present this problem is still unsolved, indeed a parameter that in the EP range is rapresentative of the acccelerogram intensity level, intended as the plastic engagement level demanded to the structures and then as the earthquake destructiveness level, has not yet been found.

Current studies, based on an energetic approach (Bertero 1988), have not yet attained to an "energetic" quantification of an accelerogram which is directely related to its potential destructiveness. Other proposals (Conte 1990) (Saragoni 1981 e Araya 1984) seem to give more adequate indications for the destructiveness estimate. However, these are qualitative evaluation methods of the destructiveness of a known accelerogram, on the base of which it is not yet possible to attain the definition of guide criteria for the generation of accelerograms with the same destructiveness level.

At present, according to the main codes in force, it is necessary to define the seismic input characteristics basing them on the traditional concept of the elastic response spectrum. Non-linear responses, produced by spectro-compatible artificial accelerograms, can be treated with a statistical approach. This approach is based on the definition of characteristic response levels, that is, levels probabilistically defined.

3 RESEARCH METHODOLOGY

The results of a research to formulate a criterion to estimate, with a predesignated reliability, the non-linear response of a structure, using a limited number of seismic inputs, are presented in this work.

The research is structured as follows.

1. Generation of a large number of similar artificial accelerograms, characterized by the same response spectrum, by the same duration, by the same maximum acceleration envelope shape.
2. Response computation of EP SDOF systems subjected to generated accelerograms in a wide range of natural frequencies that are typical for structures.
3. Statistical distribution calculation of the responses estimated as mean value of the responses obtained using a limited number of generated accelerograms.
4. Evaluation of the ratio between characteristic values of the true responses and of the estimated ones; this ratio defines an estimate amplification factor for a given exceedig probability of a response target value.
5. Reliability level evaluation of the estimated response for different amplification factor values.

4 PARAMETERS USED IN THE ANALYSES

Thirty accelerograms have been generated using the SIMQKE program (Gasparini 1976). This procedure uses the following generation control parameters:

- elastic response spectrum = S2 of (GNDT-CNR 1984) response spectrum;
- seismic input total duration = 20 s;
- maximum peack ground acceleration = 0.35 g;
- acceleration envelope curve in the time dominion = trapezoidal envelope with constant threshold (intense phase) ranging from t=2s to t=17s.

The shape effect of the envelope curve was previously investigated and it was pointed out that accelerograms with a relatively short intense phase present the smallest scatterings (Mezzi & alt. 1990,91). Accelerograms characterized by an intense phase (maximum acceleration threshold) of 6 seconds gave a mean value of the maximum calculated diplacement variation factor equal to 25.8%, for the natural periods investigated. The mean variation factor became 28.6% for accelerograms with a very short intense phase and rose to 31.6% for those with an intense phase threshold equal to 15 s. In the present study accelerograms with a long intense phase have been considered because they show the maximum scatterings in the response.

Twenty-four EP SDOF systems with a natural period ranging from T=0.2s to T=2.5s, in 0.1s steps, have been considered. Systems have a fy=0.25 plastic threshold. The plastic thresold is defined as the ratio fy=Fy/Fresp, in which Fy is the model yielding force, and Fresp is the maximum elastic response force calculated using the same accelerogram generation spectrum.

5 ANALYSES RESULTS

Every system response for each of the thirty generated accelerograms has been calculated. The maximum model displacement has been chosen as the representative parameter of the EP response.

For this parameter, in Figure 1, the mean value spectrum (continuous line), the spectrum of the values corresponding to the non-exceeding probability of 64% and 36% (dashed lines) and of those corresponding to the non-exceeding probability of 95% and 5% (dotted lines) are reported. The coefficient of variation spectrum is reported in Figure 2.

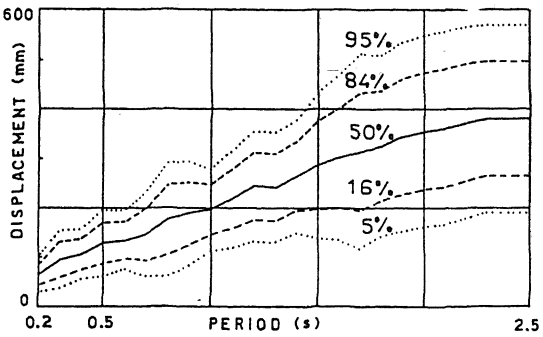


Figure 1. EP Response spectra. Characteristic values for non-exceeding probabilities.

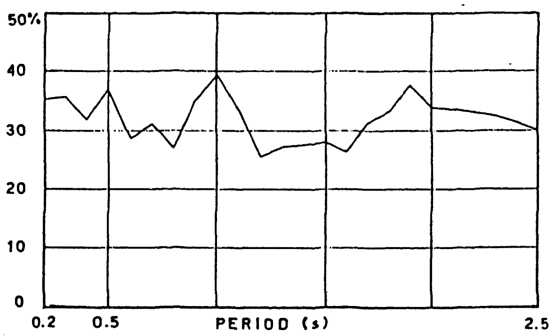


Figure 2. Coefficient of variation spectrum.

Response scattering, evaluated using the r.m.s., is greater than 30% and does not vary significantly with the varing of the natural period. Therefore, it depends principally on the excitation characteristics. In many cases, the largest response deviation is three times greater than the r.m.s. (see Figure 3): the scattering in absolute terms is considerable. It seems that the excesses number tends to exceed that corresponding to the normal distribution. At the moment this aspect has not been closely examinaed and a normal response distribution has been considered.

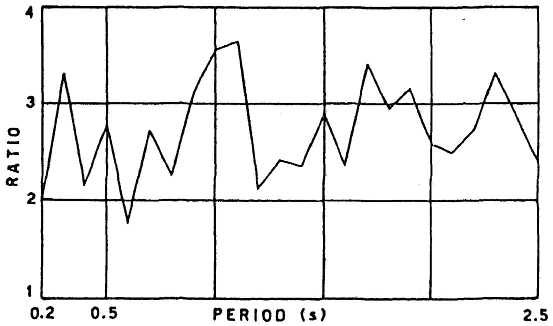


Figure 3. Ratio of the maximum deviation to r.m.s. spectrum.

The mean responses obtainable by a limited number of accelerograms, extracted from the total of the generated accelerograms population, have been calculated. In particular, the mean responses of sets of four accelerograms (27405 combinations) and eight accelerograms (5852925 combinations) have been considered. These choices have been made referring to more recent codes (EUROCODE 1984 & GNDT 1984 & AUTOSTRADE 1990) that provide for the use of 4 accelerograms and with the aim of verifing the effect of using a largest number of accelerograms. The sets of four and the sets of eigth populations are characterized by a mean value, Qm, which is equal to that of the responses population, Rm, whereas the r.m.s. of the combinations population, Qs, is lower than that of the responses population, Rs. Moreover, the r.m.s. of the sets of eight population, Qs(8), is obviously lower than that of the sets of four, Qs(4).

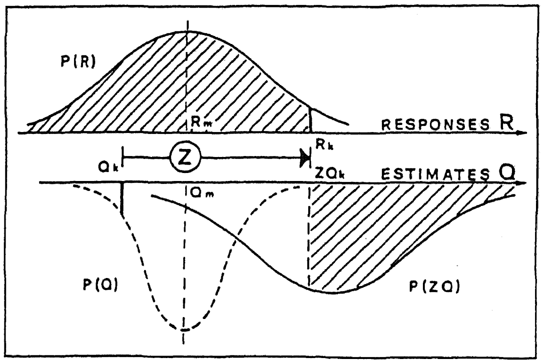
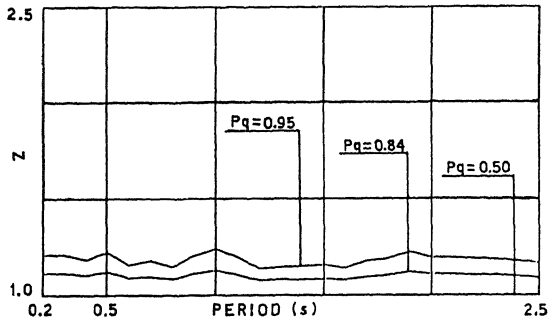


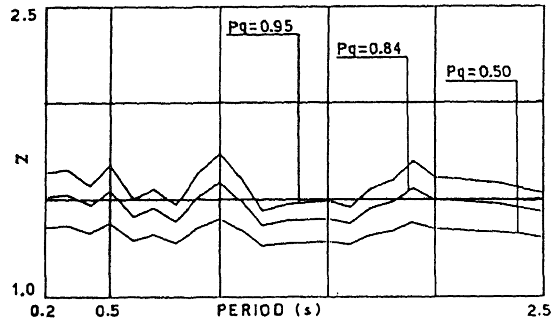
Figure 4. Z Factor.

It is possible to calculate the ratio Z=Rk/Qk between a characteristic value of the responses population, Rk, associated with a given non-exceeding probability Pr=P(R<Rk), and a characteristic value of the combinations population, Qk, associated with a given exceeding probability Pq=P(Q>Qk). The meaning of the Z factor is graphically explained in Figure 4. It can be considered as an amplification factor of the estimated response, Q, which assures a "modified estimate", characterized by a given exceeding probability of a "target" response.

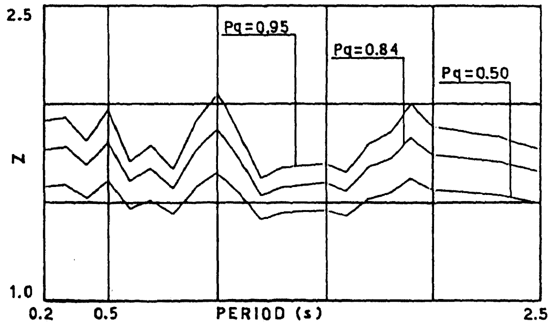
Z factors for different target values Rk, corresponding to different values of their non-exceeding probability, Pr, have been calculated. In particular the following levels have been considered: Pr=0.5 (Rk=Rm), Pr=0.84, Pr=0.95. With regard to the estimated responses, Qk values with exceeding probability of 0.5 (Qk=Qm), 0.84 and 0.95 have been considered.



a) Target Pr=0.5.



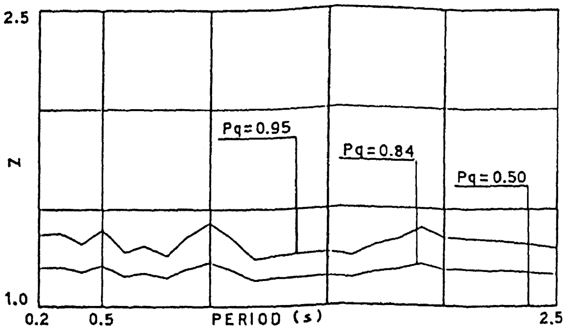
b) Target Pr=0.84.



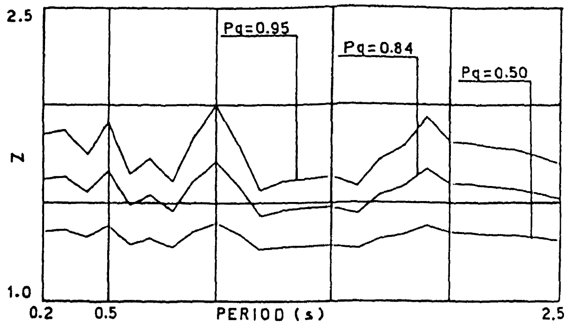
c) Target Pr=0.95.

Figure 5. Z Factor response spectra for estimates Q(8).

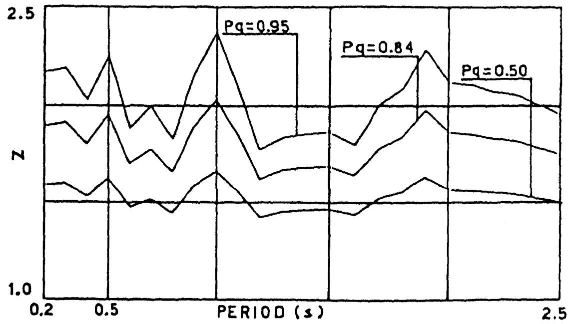
In Figure 5 a), b), and c) Z factor spectra for the three levels of the target probability Pr, considering the Q(8) estimates, are represented. In each graph the three curves corresponding to the three considered Pq levels are reported. The graphs show a substantial invariability of the Z factor with respect to the natural period of the structure. This indipendence of the natural period can be found also considering the analogous Z spectra calculated referring to the Q(4) distributions (see Figure 6 a,b,c). The Z peaks increase corresponding to the greatest Pr and Pq values, that is when the target also includes the most scetterig values and that differ the most from period to period (see Figure 3).



a) Target Pr=0.5



b) Target Pr=0.84



c) Target Pr=0.95

Figure 6. Z Factor response spectra for estimates Q(4).

A comparison of Figure 5 and 6 shows how the number of accelerograms used to evaluate the response estimate (4 or 8) does not give relevant Z value differences, except in the case when Pr and Pq values are high.

Considering the Z uniformity it is possible to refer to its mean value Zm, considered constant for every period. When Pr=Pq=0.84 the Zm factor for the Q(4) distribution is equal to 1.11 times that calculated for the Q(8) distribution.

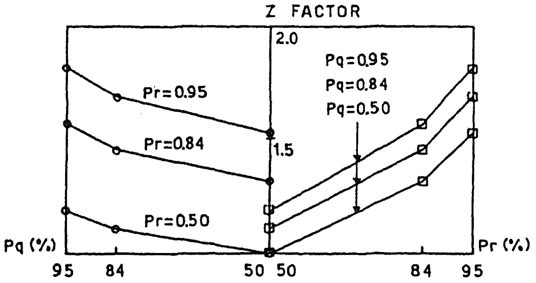


Figure 7. Z Factor sensitivity.

On the other hand, the Zm factor varies considerably with Pq variation and mostly with Pr variation. Figure 7 shows the Zm values with Pr and Pq variations referring to Q(8) distributions.

To better understand the significance of the Z factor it is useful to introduce the estimate reliability concept. Such reliability can be defined as the probability, P(ZxQ>R), that the value of the modified estimate, ZxQ, of the response is not exceeded by the response of a generic accelerogram and therefore can be evaluated with the expression:

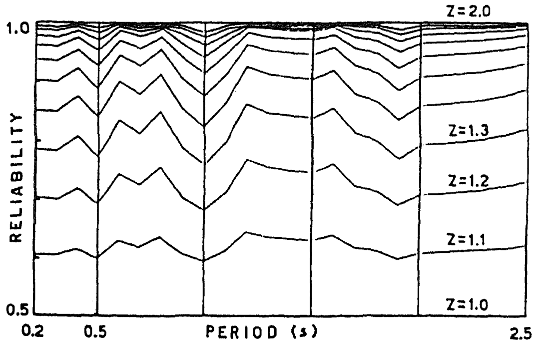
$$W(Z) = Z \times \int_{-\infty}^{+\infty} p(Z\times Q) \int_{-\infty}^{Z\times Q} p(R)\, dR \quad dQ$$

For example, the reliability levels corresponding to different choises of Rk and Qk, or of the Pr and Pq levels, are reported in Table 1, referring to the Zm values of the Q(4) and Q(8) distributions calculated for the model with natural period T=1 s.

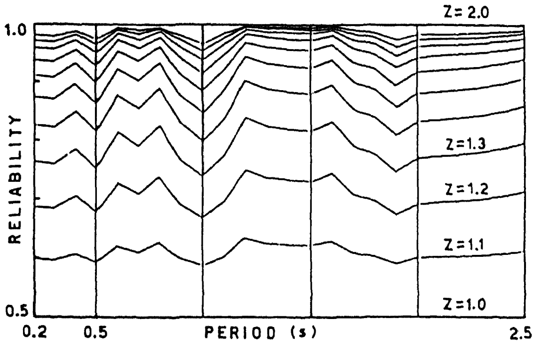
Table 1. Reliability values W (model T=1s)

	Pq					
	0.50		0.84		0.95	
Pr	Q(4)	Q(8)	Q(4)	Q(8)	Q(4)	Q(8)
0.50	0.50	0.50	0.69	0.63	0.82	0.72
0.84	0.80	0.82	0.92	0.91	0.97	0.95
0.95	0.90	0.93	0.97	0.97	0.99	0.99

In figure 8 a) and b) the reliability spectra are reported for different Z values ranging between 1 and 2 calculated referring to estimates evaluated with eight and four accelerograms respectively. The comparison of the figures shows how the reliability of the solutions does not significantly increase passing from four to eight accelerograms used for the evaluation of the estimate, but only with the Z amplification factor.



a) Estimates using sets of eight, Q(8).



b) Estimates using sets of four, Q(4).

Figure 8. Reliability spectra: Z factor variation from 1.0 to 2.0

Figure 9 reports the reliability curve of the solution estimated with eight accelerograms varying the Z factor. The two curves relative to the mean value and the maximum value of Z are reported, referring to the range oe the natural periods investigated. It is observed that the estimate reliability increases more rapidly for Z values up to 1.4 - 1.5. Beyond these values the reliability increase is less evident. A reliability greater than 0.8 can be reached with a Z factor of 1.35. A Z value equal to 1.5 allows to the response to be estimated with a reliability equal to at least 0.90.

This is confirmed by the analogous curves reported in figure 10, that are relative to the estimates obtained using four accelerograms.

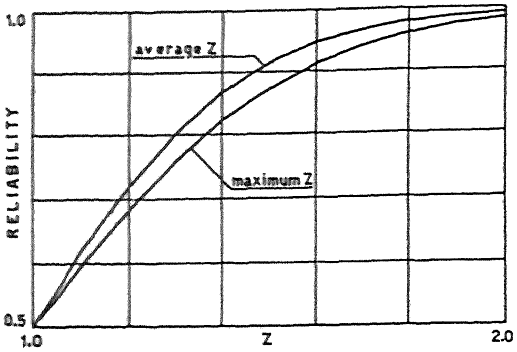


Figure 9. Reliability versus Z factor - Estimates using sets of eight, Q(8).

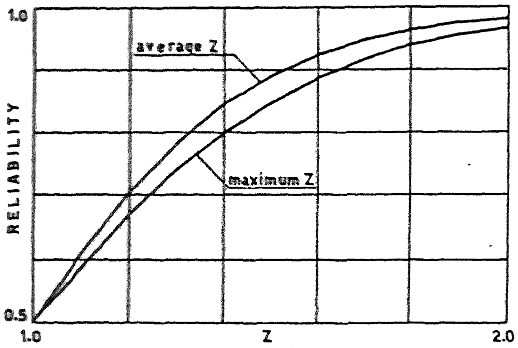


Figure 10. Reliability versus Z factor - Estimates using sets of four, Q(4).

6 CONCLUSIONS

The seismic responses of elasto-plastic structures subjected to spectro-compatible artificially generated accelerograms show a larege response scattering.

The response r.m.s. is substantially independent of the natural period of the structure. The variation factor is about 0.30.

The response can be estimated with a relatively limited number of accelerograms, i.e. four.

Predefined reliability levels of this estimate can be reached "modifying" the estimate with a Z factor.

Z factor is practically not influenced by the natural period of the structure. Furthermore, even the increase, beyond four, in the number of used accelerograms does not seem to affect the Z value.

Small Z factor increments lead to large increments of the estimated response reliability.

With Z=1.35 and using 4 accelerograms, a reliability of the modified estimate equal to 0.80 is reached. Within the analyses carried out the reliability exceeds the value of 0.90 applying a Z factor equal to 1.5.

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