PROBABILISTIC HAZARD EVALUATION IN TERMS OF RESPONSE SPECTRA

DAVRANIŞ SPEKTRUMLARI İLE OLASI DEPREM TEHLİKESİNİN DEĞERLENDİRİLMESİ

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ABSTRACT

A significative number of good quality accelerometric records of strong motion have been collected in the past two-decades. For some regions of the world (whose number is increasing) the accelerometric data bank is sufficient to allow computation of reliable spectral attenuation laws, which is a foundamental tool to calculate uniform hazard response spectra (UHRF).

In this paper it is shown that the seismicity characteristics of the area investigated can influence strongly the shape of UHRF; results that was impossible to forecast by using hazard computer codes that adopt PGA attenuation law.

The effects on the shape of UHRF caused by the Gutenberg-Richter β are comparable to that produced by soil conditions. To take into account both β and soil conditions to define the shape of Design Response Spectra in building codes, a revision of EC-8 response spectra is suggested.

INTRODUCTION

Seismic design requirements in building code are the most important tool to mitigate earthquake risk, from the standpoint of earthquake engineering. Since the sixties the majority of buildings codes adopted the design spectrum to define the seismic actions. Probabilistic hazard assessment is the procedure generally accepted to establish design response spectrum. It should be pointed out that the widely accepted principal requirement of seismic building code is to suggest design requirements in order to prevent building's collapse under major earthquake loading and to avoid damages under a moderate earthquake. So it is important to note that probabilistic hazard assessment does not give an exact and unique answer to the problem, on the other side it can provide the territory analysed a uniform risk assessment. This is a limitation of the probabilistic procedure, but unfortunately till now no procedure has been proven more adequate, at least when ordinary buildings are concerned. Some cases, for example nuclear power plants and large industrial plants, are better fitted by deterministic approaches based on the maximum expected earthquake loading. A trademark in probabilistic hazard assessment is the Cornell paper (1968), who identified the principal steps involved in hazard calculation: i.e.

- Zone source identification
- Zone source modelling
- Attenuation law
- Mathematical model.

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Cornell adopted Gutenberg-Richter law to model the seismicity, attenuation law in terms of Intensity and PGA, Poisson process to model the temporal behaviour and Newmark procedure to estimate the response spectrum. Since then strong effort have been made to improve both knowledge and methodology. Seismic source zones were individuated in the beginnings by simply contouring epicentral maps provided by instrumental and historical catalogues (Cornell & Merz, 1975), therefore assuming earthquake stationariness in space. 'Subsequently, the zonation procedure was to integrate catalogs' data with tectonic evidences obtained from geological and geophysical survey (Nowroozi, 1993). Recently a great attention has been paid to paleoseismological investigations (Kelson et al, 1993).

In the mean time historical seismicity are improving significantly, especially in Europe (Stucchi et al., 1991). To overcome the memoryless Poisson process, alternative models to describe the temporal behaviour of earthquake have been set up on the basis of mechanical models of strain build-up and release, like the time predictable, slip predictable (Anagnos and Kiremdijan, 1984) and characteristics earthquake model. From practical point of view it means the introduction of time dependent seismicity rate and probabilistic distribution like Weibull have been proven to be the more suitable.

Semi Markovian stochastic processes have been used to model zones with seismic gaps (Suzuki and Kiremidijan, 1991). The adoption of these time dependent models is still under great controversy (Kagan and Jackson, 1991). It seems that the probability of success of these models is remarkable for interplate zones earthquake, in particular in the subduction zones (Nishenko, 1985). As far as Magnitude frequency law is concerned several modified G.R. law have been suggested [truncated, quadratic], but with very poor (or any) physical justifications. Actually several hazard computer codes do not require at all the adoption of a G.R. like law, but the problem of magnitude frequency relation is still unsolved, owing to the shortness of catalog's time span respect to major earthquakes occurrence. Therefore the actual seismological knowledge suggest to adopt Poisson model for practical application (Marcellini & Slejko, 1994).

PGA attenuation relationship calculation received a boost from the massive strong motion accelerometers network deployments pushed by nuclear power plants programs in the early seventies. Since then, several attenuation laws have been suggested and presently we may say that a new attenuation law is the corollary of every major earthquake (at least as far as US, Europe and Japan are concerned).

Recently attenuation relationship have been computed also in terms of response spectra for European areas (Tento et al., 1992) (Stamatowska et al., 1990) (Pugliese et al., 1989).

Hazard methodologies presently used can be subdivided into two groups, depending whether they adopt or not Bayesian approach. Bayesian approach presents the great advantage to allow to input subjective probabilities, or in other words to include as input data geological information not feasible of quantification sensu strictu (Suzuki and Kiremidijan, 1991). In addition the method can be defined "more elegant" from a mathematical point of view. The other side of the medal is that it requires great attention in the assessment of subjective probabilities: unbelievable errors are the ordinary results obtained by no well-trained people.

In many cases adoption of simple computer codes, that use classical method are recommended, for example SEISRISK III (Bender & Perkins,1987), which is well tested.

EVALUATION OF HAZARD IN TERMS OF RESPONSE SPECTRUM

Hazard analysis is commonly performed by probabilistic approach to evaluate the expected ground motion for a given elapsed time. Generally seismic hazard is estimated in terms of $P(PGA<PGA_0/t)$ or $P(I<I_0/t)$. For design purposes the procedure widely adopted is:

1. Computation of $P(PGA<PGA_0/t)$.
2. Evaluation of the DAF (Dynamic Amplification Factor) from statistical analysis of strong motion recordings.
3. Scaling of the DAF to the assumed PGA to produce $P(PSA<PSA_0/t)$.
4. Derivation of the design spectrum from 3, assuming a design return period.

This procedure, like the one based on Newmark method adopted by Cornell (1968) leads to non uniform probability of the design spectrum.

Here a method to evaluate hazard in terms of uniform probability response spectrum is suggested and applied to a seismic test zone. The method is based on Bayesian approach and was prepared by Stanford University (Chiang et al., 1984), but some corrections made by the author.

The main features can be summarised as follow:

- Sources can be both area sources and line sources, depth of seismogenic zone can be taken into account.
- Earthquake occurrence is modelled by Poisson process, the rate λ is considered as random variable, so the marginal distribution of number of events can be written

$$\mathbf{p_N(n)=\int_0^{\S} p_N(n/\lambda) f''_\Lambda(\lambda)\, d\lambda} \qquad (1)$$

Where $\mathbf{f''_\Lambda(\lambda)}$ is the posterior distribution on λ

- Magnitude distribution follow a Binomial law, $\mathbf{p_{M_i}}$ is the probability of success on a Bernoulli trial and is considered random variable , therefore the conditional probability of r events of Mi, given the occurrence of n events is

$$\mathbf{p_R(r_{M_i}/n) = \int_0^1 p_R(r_{M_i}, p_{M_i}/n)\, dp_{M_i} = \int_0^1 p_R(r_{M_i}/p_{M_i}, n) f''_P(p_{M_i}) dp_{M_i}} \qquad (2)$$

where $\mathbf{f''_P(p_{M_i})}$ is the posterior distribution on $\mathbf{p_{M_i}}$

- The probability of r events of magnitude Mi is obtained combining (1) and (2); so the marginal distribution on $\mathbf{r_{M_i}}$ can be written

$$\mathbf{p_R(r_{M_i}) = \sum_0^{\S} p_R(r_{M_i}/n)\, p_N(n)} \qquad (3)$$

- Given Mi and source zone, the probability of exceedence of pseudo velocity response spectrum **PSV** for a given period $\mathbf{T_k}$ at the site is computed by the following

$$\mathbf{P(PSV(T_k)>psv_i(T_k)\;) = p^{*}\,P(M_J) + \left(1-(1-p)^2\right) {}^{*}P(2M_J) + ..\left(1-(1-p)^n\right) {}^{*}P(nM_J)} \tag{4}$$

where

$$\mathbf{p = P(PSV(T_k)>psv(T_k)/M_j\;)} \tag{5}$$

and the computation is performed for the whole set of periods of interest.

- Eventually the total probability **$P(PSV(T_k)>psv(T_k))$** is calculated by summing over all magnitudes and seismic sources.

RESULTS

The size of the zone analysed (18000sq km), shown in fig. 1 is typical of an Italian seismic source zone (Scandone et al., 1992).

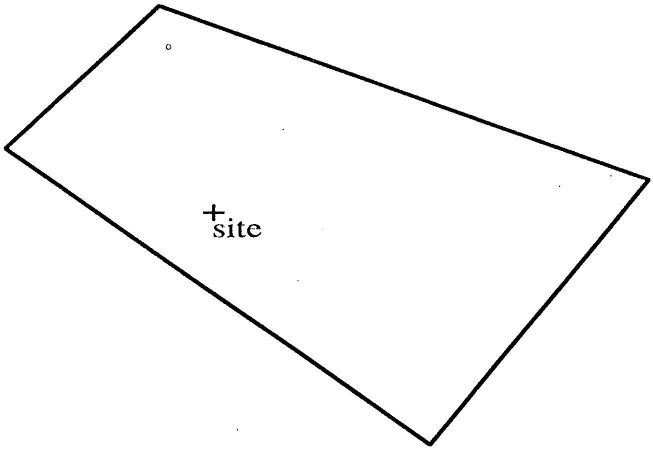

Figure 1. Seismic source zone: Area=18000sq km, λ=0.72 ev/year, $3.5 \leq M < 7$
+ is the site where hazard is computed.

The seismicity is considered homogeneously distributed within the area, with a seismicity rate of 0.71 events per year for earthquakes $M \geq 3.5$: the upper bound is M=7; the Magnitude distribution is considered to follow a log-linear Gutenberg Richter frequency law.

The aim of this paper is to evaluate the dependence of response spectral shape (DAF) on the parameters used to calculate uniform probability seismic hazard. It is important to note, as is likely to infer from eq. 2 and eq. 4, that the DAF is not influenced by the seismicity rate as above defined, (i.e. the coefficient α of the Gutenberg-Richter law); in fact the DAF is mainly dependent on the response spectrum attenuation law. In this paper the Tento et al. (1992) attenuation law is adopted; Tento et al. showed that the predicted spectral shape depends significantly on the magnitude, as reported in fig. 2, but is not influenced by the epicentral distance.

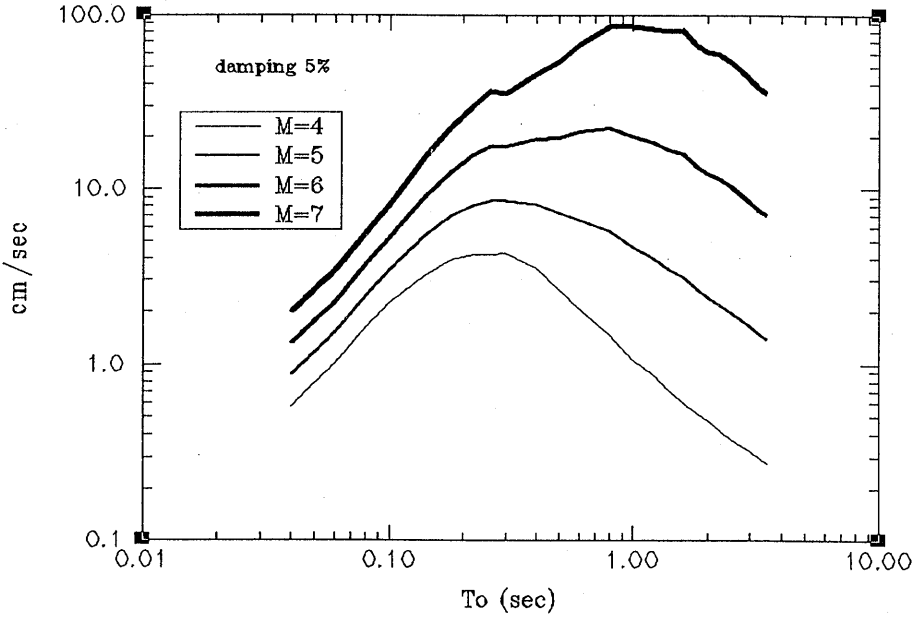

Figure 2. PSV response spectra obtained by attenuation law (Tento et al., 1992) for different magnitudes at distance 10 km and hypocentral depth=10 km.

This last result seems to contradict some common belief (mainly inferred from theoretical considerations partially supported by seismological data) that there is a spectral shift towards low frequencies according to the increasing of hypocentral distance. Actually strong motion data exhibit no spectral shift against distance; at least this evidence has been found both in Italian (Tento et al., 1992) and Yugoslav data (Stamatowska et al., 1990). The main reasons are:

1. The strong motion is composed by the same type of waves in the range of distances we are interested in (till around 150 km).
2. Considering that the attenuation is composed by the geometrical spreading and by the anelastic behaviour of the medium involved in wave propagation, the invariance of the spectrum shape simply means that $\upsilon=1$, once we adopt the ordinary definition of $\mathbf{Q=qf^{v}}$, ($\upsilon=1$ is a value heavily supported by seismological investigations).

Two factors are extremely important when spectral attenuation laws are used in hazard analysis.

a. The choice of the conditional distribution of $\mathbf{P(PSV(T_k)>psv(T_k)/M_j)}$.The majority of investigators agree to consider both PGA and PSV lognormally distributed: statistical tests conducted performing attenuation regression analysis are in favour of this hypothesis (see for example Stamatovska et al., 1990). Henceforth the PSV obtained by regression analysis are considered lognormal distributed.

b. The behaviour of standard deviation.

In general an increase of s.d. according to To is observed (fig. 3).

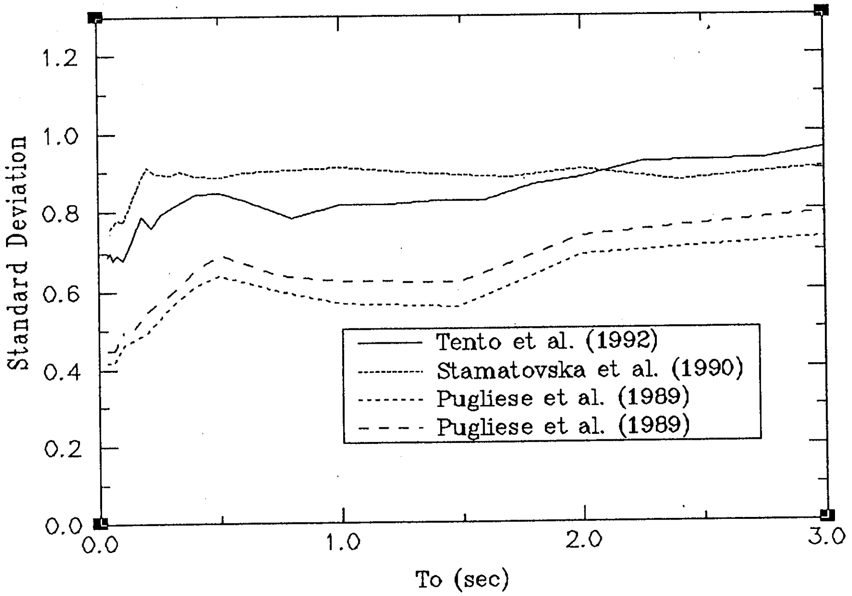

Figure 3. Comparison of attenuation law standard deviation of PSV against T_0, as obtained by different authors.

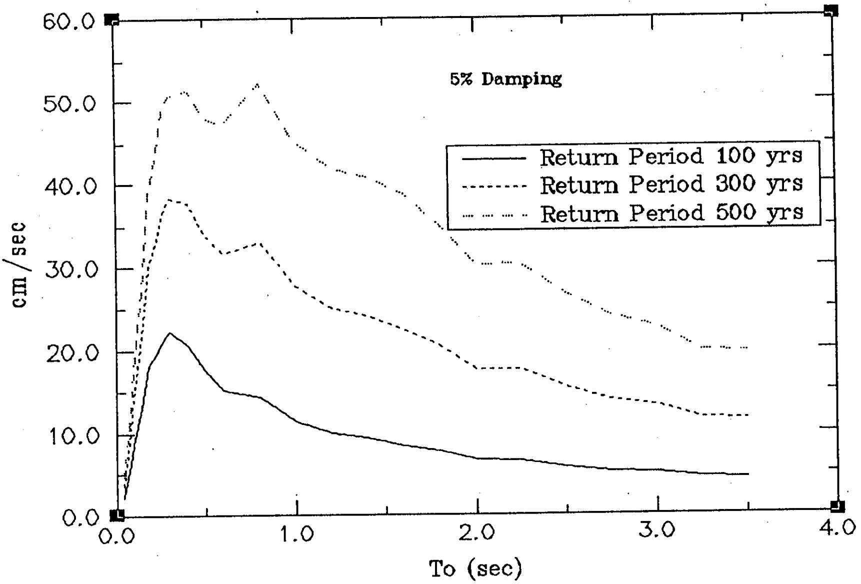

Figure 4. Uniform probability PSV for β=2 and different Return Periods.

It is understood that both the seismicity rate and the source-site distance influence the amplitude of the expected response spectrum. As an example fig. 4 shows that the uniform probability response spectrum increases significantly according to Return Period, as predicted by the above equations, because the change of Return Period is equivalent to change $\mathbf{p_N(n)}$ of eq. 1, once we consider that the earthquake occurrences follow a poissonian distribution.

With this provisos in mind we are now in the position to evaluate the principal factors influencing the DAF.

DISCUSSION

To help visual analysis of the results the DAF's are presented as 5% damping normalized PSV response spectra where the normalization is computed with regard to the area under the spectrum. The main results are summarize as follow

1. DAF against Return Period.

Fig. 5 shows the scarce influence of return Period upon the DAF; it should also be added that the variation mainly depends on the adoption of the lognormal distribution of the PSV attenuation law rather than on the Return Period itself.

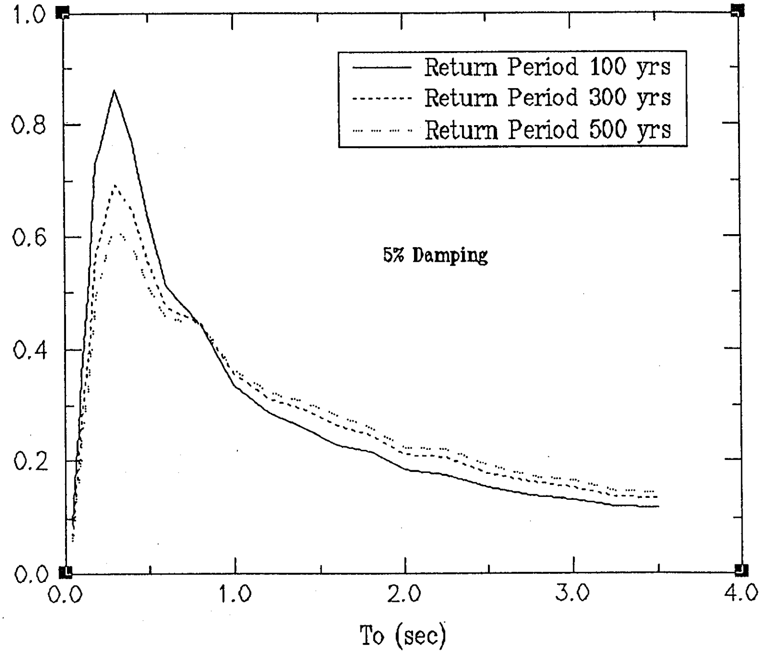

Figure 5. Normalized uniform probability PSV for $\beta=2$ and different Return Periods.

2. DAF against standard deviation of attenuation law.

If standard deviation is the same for all To, DAF remain constant, independently on the value of the standard deviation. Standard deviation could produce DAF variation only if it is not constant respect to To. Fig. 6 shows that there is no appreciable DAF modification for variation of S.D. against To usually obtained in the computation of attenuation laws.

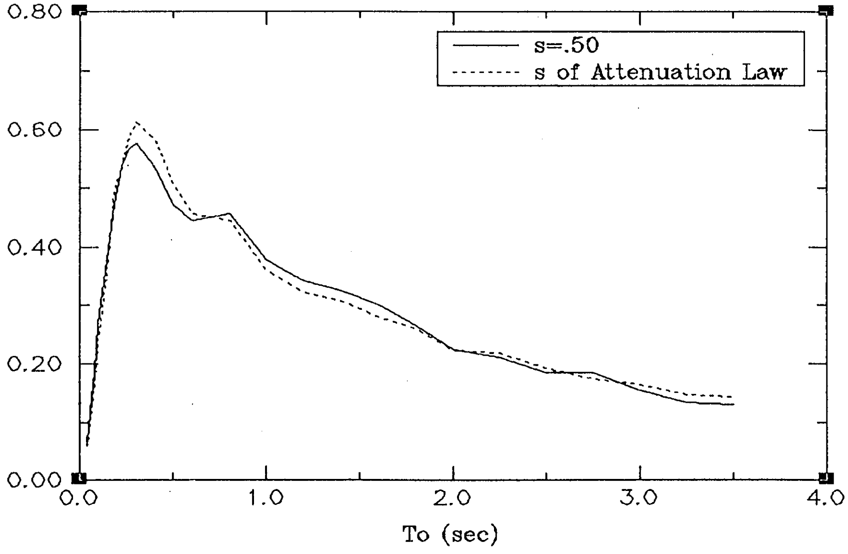

Figure 6. Normalized uniform probability PSV for constant standard-deviation and compared standard deviations obtained by attenuation law (Return Period=500y).

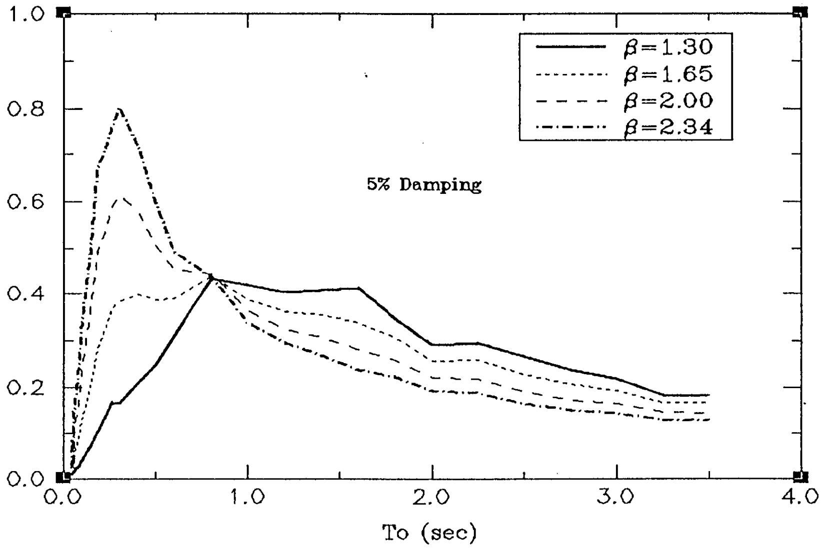

Figure 7. Normalized uniform probability PSV for 500 years Return Period for different β values.

Table 1. VALUES OF THE MAGNITUDE-FREQUENCY PARAMETER, β

REGION	β	REFERENCE
Western Nevada	2.1	Douglas and Ryall (1975)
Western United States	1.17 - 2.00	Hsieh et al. (1975)
California	2.07	Housner (1969)
San Jose, California	1.2 - 1.3	Donovan (1978)
Eastern United States	1.93	Hsieh et al. (1975)
Southern New England	2.19 (± 0.12)	Chiinnery and Rogers (1973)
New Jersey	2.17	Isacks and Oliver (1964)
Central Mississippi River Valley	2.00 (± 0.25)	Nuttli (1974)
Mexico City	1.27	Ferraes (1967a)
Circumpacific Belt	2.16	Newmark and Rosenblueth (1971)
Alpide Belt	1.70	" " "
Low-seismicity Region of World	2.88	" " "
Japan	2.81	Dowrick (1977)
New Guinea	3.1	" " "
New Zealand	2.5	" " "
Western Canada	2.5	" " "
Central America	3.34	" " "
Columbia-Peru	2.55	" " "
Northern Chile	2.0	" " "
Southern Chile	2.12	" " "
Mediterranean	2.5	" " "
Iran-Turkmenia	2.7	" " "
Java	2.16	" " "
East Africa	2.0	" " "

3. DAF against Gutenberg Richter β.

Table 1 shows that β can take values between approx 1.2 and 3; that is to say, from our point of view, the conditional probability $\mathbf{p_R(r_{Mi}/n)}$ (eq. 2) can undergo dramatic changes that strongly influence eq. 4, given the behaviour of attenuation law presented in fig. 2 . This DAF dependence on β is confirmed by fig. 7, despite the range of β considered is less than the one shown in Table 1.

In fig. 8 variation of DAF is presented for 300 and 500 years Return Period: the β values represent the higher and lower β boundaries of Turkey seismic source zone, according to Erdik et al. (1985): also in this case the DAF differences are well pronounced.

4. DAF against Gutenberg Richter β and against site conditions.

A simulation has been conducted using the viscoelastic model SHAKE (Schnabel et al., 1972). Fig. 9 shows the DAF computed at the free surface considering a clay layer with Vs=200m/sec overlying a bedrock with Vs=1000m/sec per different layer' thickness, between 0 and 50m. The accelerometric record at Tolmezzo site (PGA=0.37 g) of the May, 6, 1976 M=6.4 Friuli earthquake has been taken as input motion.

Visual inspection of fig. 8 and fig. 9 bring to the conclusion that site conditions and β can affect the DAF in comparable way .

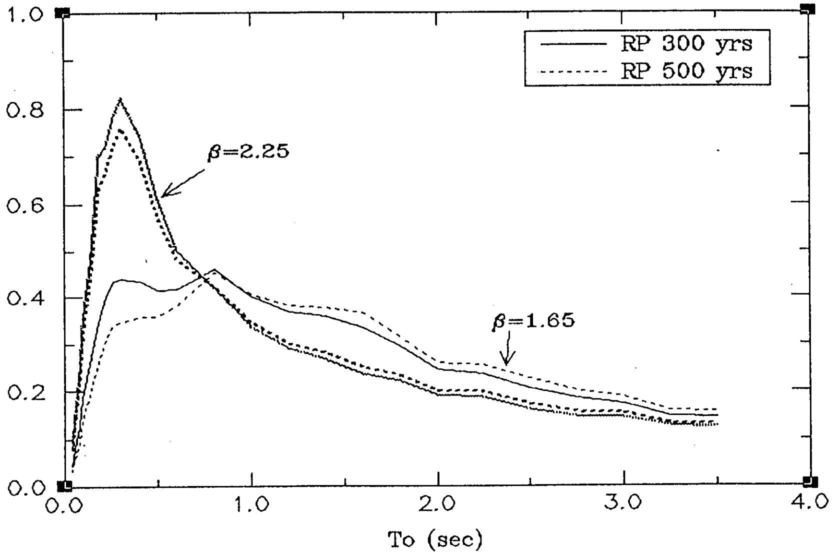

Figure 8. Normalized uniform probability PSV for RP=300, 500 years and β=1.65 and 2.25.

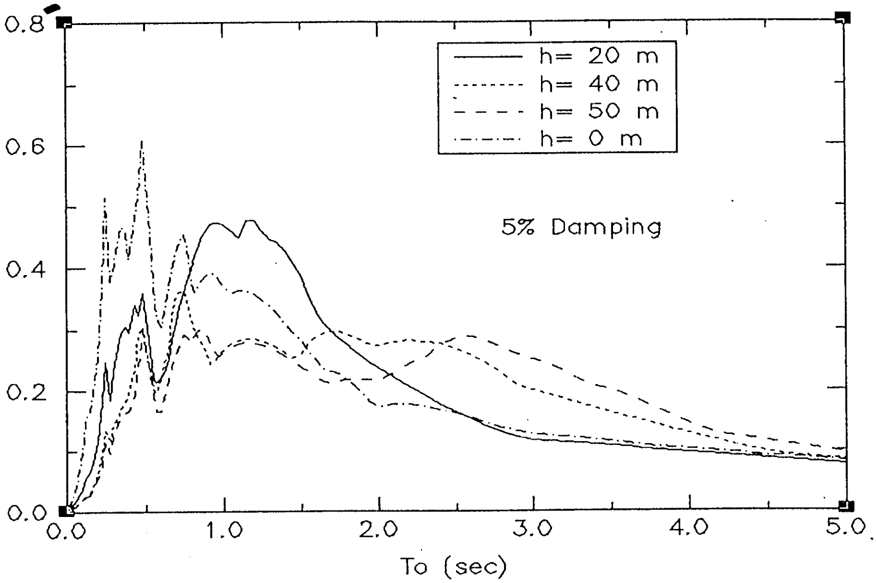

Figure 9. Normalized PSV obtained using SHAKE program considering a clay layer of depth h and Vs=200m/sec overlying a bedrock with Vs=1000m/sec (h=0m means outcrop)

CONCLUSIONS

It has been demonstrated that the influence of β upon uniform hazard spectrum is comparable with the influence of site conditions.

The main problem now is the translation of results into practical application; i.e. building codes, considering that is important to keep a reasonable and workable balance between over-simplicity and undue complexity. In principle the assessment a given design spectrum is equivalent to fix the level of acceptable risk, therefore it involves political decisions; so we give some suggestion under the hypothesis of validity of the Seismic Eurocode (EC-8) philosophy.

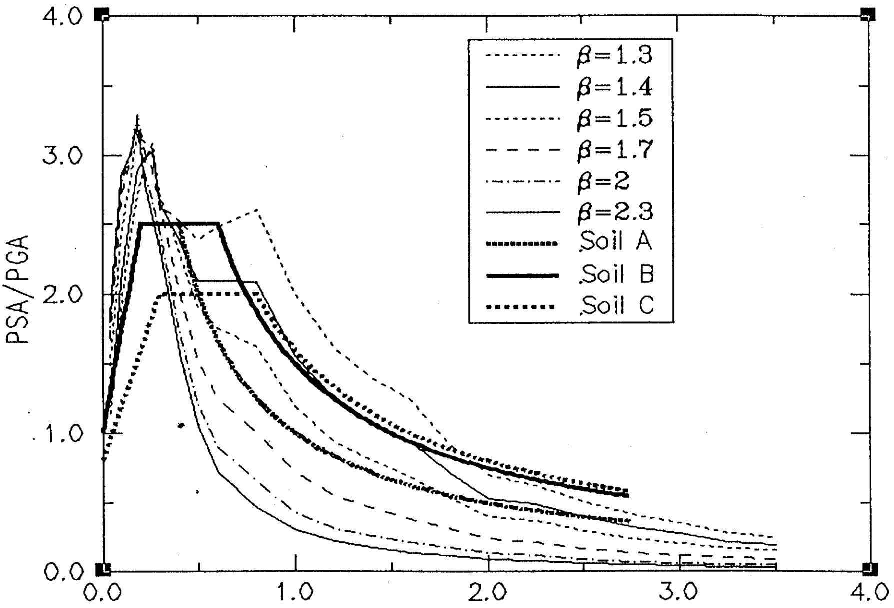

Figure 10. Comparison of normalized uniform probability PSA obtained for different β values, with EC-8 Design response spectra for the 3 types of soils.

In fig. 10 DAF (in this case 5% damping PSA normalized to PGA), obtained using different β values are superposed to EC-8 design spectrum shape for the 3 soil types.

It is possible to note that decreasing of β causes peak reduction, as well as enlargement of period range.

We can now integrate the results obtained into the requirement prescribed by EC-8; therefore the suggested spectra depend both on soil sites and Gutenberg-Richter β.

The new design spectra (that we can call "EC-8 revised") are summarized as follow:

1. The 5% damping design response spectrum, normalized to PGA can be describe by the fig. 11.

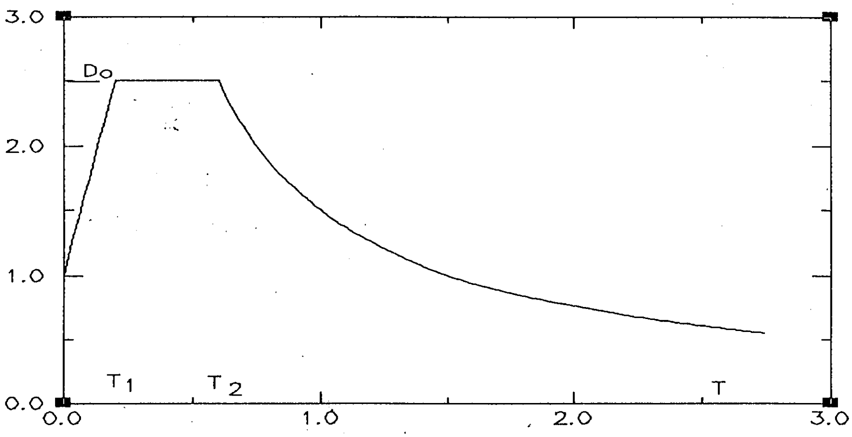

Figure 11

where the spectrum D(T) is defined

$$D(T)=S(1+\frac{T}{T_2}(D_0-1)) \qquad \text{for } 0<T<T_1$$

$$D(T)=SD_0 \qquad \text{for } T_1<T<T_2$$

$$D(T)=S(D_0\frac{T_2}{T}) \qquad \text{for } T>T_2$$

That is to say the same as in EC-8.
2. The coefficients reported in Table 2 are modified and integrated respect to EC-8 in order to account for G-R β variation.

Table 2. Parameters of the design spectrum

β value	Soil type	T_1(sec)	T_2 (sec)	D_0
β1	A	0.1	0.3	2.8
β1 β2	B A	0.1	0.4	2.6
β1 β2 β3	C B A	0.2	0.6	2.5
β2 β3	C B	0.3	0.7	2.3
β3	C	0.4	0.9	2.0

Soil types according to EC-8 (A:Vs>800 m/sec; B: intermediate; C: Vs < 200 m/sec)
β=β1 for β>2; β=β2 for 1.5<β<2; β=β3 for β<1.5

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