REVIEW ON SEISMIC HAZARD ASSESSMENT IN GREECE

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ABSTRACT

In this presentation a review of the methodologies and techniquess applied in Greece for seismic hazard assessment and strong motion simulation are presented and discussed. Emphasis is given to the uncertainties involved and to the limitations of the useability of the results.

In estimating the expected maximum ground motion parameters, two main approaches are used: the pure statistical and the semi-statistical approach in the sense that before applying a cetain earthquake occurrence law, the modelling of the seismic sources based on seismotectonic criteria and their potentiality is evaluated.

The statistical approach uses the Extreme Values method introduced by Gumbel[9]. Two implementations of this model were used in the present study. The first, introduced by McGuire[21], is based on the total probability theorem and a given attenuation law, while the second, introduced by Bender and Perkins[4], allows earthquakes within a specified zone to be normally, rather than uniformly distributed. In order to calculate the expected response spectra, the method EQRISK, introduced by Anderson and Trifunac[2] and implemented by Anderson[1], is used.

For specific case histories, the expected response spectrum at a site from an earthquake with given parameters calculated by EQRISK, serves as the target in simulating the expected accelerogram, using the technique introduced by Gasparini and Vanmarke[8]. For comparison reasons, all the above methodologies are applied in estimating the seismic hazard of the city of Athens, the capital of Greece. The results expressed in PGA having 90% to be the maximum during the next 25, 50 and 100 years are in close agreement. Using the spectral approach a synthetic expected accelerogram in the case of an event with epicentral distance D=25 km from Athens, magnitude M=6 and depth of 10 km is also constructed.

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INTRODUCTION

The reliable estimation of seismic hazard parameters, such as maximum expected earthquake acceleration or velocity, is an important issue for earthquake resistant planning and risk mitigation of highly urbanised areas.

During the last ten years or so a variety of empirical, semi-empirical and theoretical methods have been proposed for simulating the expected strong ground motion as well as statistical and semi-statistical approaches for evaluating the potentiality of earthquake sources and assessing the overall seismic hazard of an area.

However, despite of the tremendous scientific efforts during the last few decades towards the probabilistic approach of the problem, there is still no method globally applicable or accepted.

Studies of the first category involved several assumptions concerning the various fault parameters, geological structure, propagation path, attenuation laws, etc. Because of our limited knowledge on the degree of complexity of the tectonic setting, irregularity of the wave propagation pattern and above all the lack of data base of high quality strong motion records, the cumulative effect of the uncertainties involved confines the paractical application of such methods. On the other hand, the statistical approach based on past seismic history, earthquake occurrence and attenuation laws, usually without considering the physical properties of the source, results on "average" expected peak ground motion parameters and thus, the above are used for the general hazard assessment of a broad area. For specific structures, these values serve as the scaling factors in the simulation procedure that follows, for constructing acceleration time histories using empirical strong motion parameters.

Greece is one of the most seismically active countries is the world and the most active in Europe. About 2% of the whole world's seismic energy release is released within the Greek territory, Bath[3], an area amounting to only 0.09% of the total area of the world, and it is truly a "vast seismological laboratory".

The long documented seismic history of Greece reports many catastrophes due to earthquakes. Thus, the earthquake phenomenon, posing a continuous threat to Greek social and economic life, is among the research problems which have been studied for many years with increasing efforts. The reliable estimation of seismic hazard and seismic risk and developments of means of mapping them in an understandable fashion to the final users, are problems which most urgently require answers.

In the present work a review of the methodologies applied in Greece for seismic hazard assessment and strong motion simulation will be presented with special emphasis to the uncertainties involved and their limitations. These limitations are mainly due to the lack of high quality strong motion data from near field observations. The comparison of these methods is attempted through their application for the estimation of the seismic hazard of the city of Athens, the Capital of Greece, which is a heavily populated area, and where a variety of soil conditions exists.

STATISTICAL APPROACH

The statistical models of seismic hazard calculation used in Greece consist of

a. empirical formulae based on available macroseismic data,

b. statistical distribution laws for earthquake occurrence in time and magnitude and

c. attenuation laws describing the decay of seismic ground motion with focal distance.

Expected Magnitude Estimation

Two methods based on Gutenberg & Richter frequency- magnitude relationship and on the Extreme Value distribution of magnitudes have been used. They only require an earthquake catalogue containing the events that occurred within the epicentral distance with potential to affect the site(s) under consideration. Both of them assume that the seismicity within the area or zone is uniform; that is, each point within the area has the same probability of being the epicenter of a future event.

The basic relationships for the first method are:

$$M_{P1} = M_1 - (\log[\ln(1-P)]/b \quad \text{and} \tag{1}$$

$$M_{PT} = M_{P1} + \log T/b \tag{2}$$

where M_{P1} and M_{PT} are the annual and T-year magnaitude which are expected as maximum with probability P respectively. The M_1 is the most probable annual maximum (mode) given by the ratio of a over b where a and b are the constants of the normalized to one year Gutenberg-Richter's formula:

$$\log N_1 = a - bM \tag{3}$$

This method was used in Comninakis[5] work for assessing the seismic hazard of Greece.

While the previous model makes use of all available data this statistical approach uses only the maximum parameter under consideration per unit time.

For the magnitude calculations the III-type asymptotic distribution is used. It has the form:

$$G(m)_{III} = \exp[[-(\omega-m)/(\omega-u)]^{k}], u>0, m\leq\omega, u<\omega \quad (4)$$

where $G(m)_{III}$ is the probability that the magnitude m will be the maximum during the unit time, v is the upper bound magnitude and the u is the characteristic largest value.

Then using the previous symbols, parameters are expressed by the relations:

$$M_1 = \omega-(\omega-u)\ (1-1/k)^{1/k} \quad (5)$$

$$M_T=\omega-(\omega-u)[(1-1/k)/T]^{1/k} \quad (6)$$

$$M_{P1}=\omega-(\omega-u)(-\ln P)^{1/k} \quad \text{and} \quad (7)$$

$$M_{PT}= \omega-(\omega-u)\ (-\ln P)^{1/k}/T^{1/k} \quad (8)$$

The above statistical model has been applied for maximum magnitude calculations in Greece by Makropoulos[13], Makropoulos and Burton[14], Drakopoulos and Makropoulos[7]. The parameters of Eq.4 and. their complete variance-covariance matrix were calculated using the program written by Makropoulos and Burton[15], based on Marquardt[20] algorithm.

Expected Ground Motion Parameters Estimation

The statistical model used for seismic hazard assessment in terms of maximum expected ground motion parameters such as PGA, PGV or PGD is the Gumbel's I-type asymptotic distribution of extremes. It has the form:

$$\Phi(x)_I = \exp[-\exp[-a(x-u)]],\ a>0 \quad (9)$$

the parameters u and a are calculated using the least-squares method.

Using the same notation as for the III-type asymtote the relations for the largest ground motion parameter Y, are:

$Y_1 = u$, $Y_T = u+\ln T/a$, $Y_{p1} = 1-\exp[-\exp[-a(Y-u)]]$ and

$$Y_{PT}=1-\exp[-T\exp[-a(Y-u)]] \quad (10)$$

The above relations, along with the acceleration attenuation formula, proposed by Makropoulos[13]

$$PGA = 2164.e^{0.70m}\ .\ (R+20)^{-1.80} \text{ in cm/sec}^2 \quad (11)$$

were used in this study, whereas for the PGV and PGD, the published attenuation formulae were applied.

The above models, like any other statistical model, are heavily based on the quality and the completeness of the catalogue of earthquakes used. Since this requirements are hardly reached by any catalogue for the whole period covered, especially for the beginning of this century. The resulting hazard parameters must be critically evaluated, even when they are used for background information. This is mainly the case when the model makes use of the whole data set like the Gutenberg & Richter's model and to a lesser degree, when only the maximum values and hense more complete, are used (Extreme method). Furthermore the estimation of the complete variance-covariance matrix of the parameters involved makes their evaluation more objective.

SEMI-STATISTICAL APPROACH

The basic idea of such an approach, first proposed by Cornell[6], came from the necessity to take into account the potentiality of the tectonic features of the area (e.g. parameter at the site). Thus, before any calculation, the modeling of the earthquake sources is performed on the basis of seismicity pattern, geology and tectonics. The seismicity parameters of each source (e.g. seismic rate, minimum and maximum magnitude), the geometrical parameters (e.g. distance and azimuth to the site) and the appropriate atttenuation law are then the input to the statistical model, used to calculate the contribution of each source to the final seismic hazard of the area.

For engineering purposes we are usually interested in determining the probability of occurrence of at least one event greater than m in time t. This is given by the formula:

$$P_1(M>m,t)=1-\exp[-N(m)t] \qquad (12)$$

The method considers three types of sources, the point, line, and areal source. When Eq. 12 is applied, the number of events N(m) takes the values of:

$$N(m)=N(M)/T, \quad N(m)=N(M)/LT \quad \text{and} \quad N(m)=N(M)/AT \qquad (13)$$

for the point, line and areal source respectively.

The attenuation laws applied are the same as in the previous section. Then the procedure of calculating the seismic hazard at a site starts from the estimation of the seismicity rate of each source surrounding the site. The contribution of each one of them to the final hazard is next calculated through the relative attenuation law and the cumulative effect is estimated.

A modification of Cornell's method is the so called McGuirer's[21] technique. It considers areal seismic sources and makes use of the total probability theorem:

$$P(a \geq a) = \iint_{r\,m} P(A \geq a/m,r) f_M(m) f_R(r) dmdr \quad (14)$$

where $f_M(m)$ and $f_R(r)$ are the cumulative distribution functions of magnitude and distance respectively, $P(A>a)$ is the probability of an acceleration, a, being equalled or exceeded at a site.

Once the $P(A \geq a)$ has been calculated for the occurrence of one earthquake of arbitrary magnitude and location in a source area, the annual expected number of events from that source area that cause an acceleration value a or greater is obtained by multiplying the single-event hazard by the expected number of events during one year. The total expected number of events is obtained by summing the expected number from each source area. The total annual hazard is then given by:

$$R_A = 1\text{-}\exp(-N_A) \quad (15)$$

where N_A is the expected number of occurrences. The method allows the uncertainties of the attenuation law to be taken into account. This method was applied for the seismic hazard assessment in Greece by Makropoulos et al.[16].

The assumption concerning the uniformity of the seismicity within a seismic source zone is the same as the one mentioned earlier for the statistical approaches. The consequense of such an assumption may be the existence of abrupt changes in the rate of earthquakes at a source zone boundary and hence the calculated probabilistic ground motion levels may differ substantially at sites a few kilometers apart. To overcome this effect and some other shortcomings observed when applying the McGuire technique like the closest site-to-rupture distance in fault-rupture model and its influence on ground motion estimation, Bender and Perkins[4] implemented a computational technique which allows: (a) earthquakes within a zone to be normally rather than uniformly distributed, (b) to perform magnitude smoothing for closest distance rupture, (c) to perform distance smoothing for ruptures along artificial faults and (d) to perform smoothing of accelerations calculated using fault ruptures.

This method has also been applied for the Greek Hazard estimation by Makropoulos et al.[17].

The experience earned by the application of these methods shows that they are as it is expected, sensitive to the imput parameters like the attenuation law, the determination of the seismic source zones, etc. However, it is well known that the precedures used in delineating the seismic source zones are ill-defined and no single standard exists. Difficulties arising from our limited knowledge on the degree or complexity of the tectonic setting, irregulaity of the wave propagation pattern and above all the lack of data base of high quality strong motion records especially from near-field observations call for a careful treatment of the output results.

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SPECTRAL APPROACH

For site-specific hazard evaluation the spectral approach leading to the simulation of expected strong motion record at the site involves the following steps:

1. The expected response spectra for site conditions and damping factors with given probability levels are calculated followıng Anderson and Trifunac[2] methodology, as inplemented by Anderson[1]. This is accomplised by independent scaling of spectral amplitudes in several frequency bands which all have the same probability of being exceeded in strong earthquake shaking, the so called "Uniform risk spectrum" appropriate to the site, EQRISK method.

2. For a specific case history the expected response spectrum at a site from an earthquake with given parameters, calculated above, serves as target in simulating the expected accelerogram, using the technique introduced by Gasparini and Vanmarke[8], SIMQKE method. The method is based on summing up a series of sinusoidal waves and multiplication of the power of the steady-state motion produced by a deterministic envelope function in order to simulate the transient character of a real earthquake. The envelope can accommodate three types of functions, namely trapezoidal, exponential and compound. The flow chart of this multi-methodological approach is shown in Fig.1. In the following, for comparison reasons, the resalts of such a multi-methodological approach applied for the estimation of seismic hazard of the city of Athens, capital of Greece, are presented.

APPLICATION IN ATHENS (GREECE) SEISMIC HAZARD ASSESSMENT

This part is heavily based on the work of Makropoulos et al.[19] and only the input data and the resulting hazard parameters are presented and discussed. Thus, the earthquake catalogue used is the one of Makropoulos et al.[18], which covers the instrumental period from 1900 up to 1987. The acceleration attenuation law, Eq.11, is used in all methods. For the McGuire, Bender and Perkins techniques the geometry of the three seismic source zones considered as capable to influence the hazard of Athens are taken from the division made by Papazachos[22],Fig.2, while the seismicity parameters of each one of them are estimated using the aforementioned catalogue. The results are listed on Table 1.

TABLE1.Zone Regression Parameters

	Z8a	Z8b	Z11
a	3.86	2.62	3.52
b	0.80	0.64	0.79

In estimating the expected synthetic accelerogram in the case of an earthquake with parameters similar to the one occurred in the 1914, October, 17th at the same distance from Athens, the EQRISK is first used with a point source zone and the resulting response spectrum for a damping factor of 0.02 of the critical is introduced to SIMQKE as the target spectrum. The transient character of the event is simulated by the compound type envelope function. The envelope parameters are estimate by using the duration-magnitude formula of Hisada and Ando[10], and the time ratios of the control points versus magnitude given Jennings et al[11].

Results and Discussion

Table 2, shows the results obtained following the statisti- cal (HAZAN), and semi-statistical approaches (SRAMcG,SEISRISK). These are expressed as the peak ground acceleration values having 90% probability to be the maximum during the next 25,50 and 100 years for the town of Athens. From these values, which are in relatively close agreement, we may conclude that the area of Athens is characterized by moderate level of seismic hazard. However the values obtained by McGuire's method are higher than the ones resulting from the other two methods. This tendency has been systematically observed in previous applications of these methods Makropoulos et al[17], taking into account that the SEISRISK method uses as input the same zoning configuration, this difference may be due to the way of calculating the contribution of each source in the final estimate.

Table 2. Acceleration values cm/sec^2 for 90% of NBE in T years

T	HAZAN	SRAMcG	SEISRISK
25	195.75	253.36	172.66
50	222.95	276.43	206.01
100	250.15	386.55	243.29

Figure 3, shows the results of the spectral approach using the EQRISK computer program. The response spectra shown in this figure are for a hard site case and correspond to the values with 90% probability to be the maximum in the next 25, 50 and 100 years. The acceleration spectra have their maximum around 0.2 seconds whereas the pseudovelocity values take their maximum at 0.5-0.6 seconds and the displacement from 3 to 5 seconds. The potential seismic sources are mainly situated relatively far from Athens and at a distance favoring the concentration of seismic energy around the 0.5-0.8 seconds. In addition most of the buildings in Athens are highrise structures with natural periods within the same range. This coupled with the fact that spectral velocities are maximized in this range, Fig. 2, should attract the engineer's special attention mainly to the velocity spectral values.

Finally, Fig. 4a,b, shows the response spectra and the synthetic accelerogram expected in case of an earthquake 25 km from Athens with M=6 and 10km depth. This can provide the designer with additional information for specific cases.

CONCLUSION

The hazard estimation methods used presently in Greece and presented here, are capable of revealing the main features of the seismic regime of the area. However the degree of their reliability is, as already mentioned, directly propotional to the quality and completeness of the data involved. This condition is difficult to be fulfiled even for a country with high seismicity like Greece. Furthermore the limited number of strong motion records, force us to adopt formulas derived from areas of similar tectonic characteristics or use, as in the present case, "average" ones like the Eq.11. The knowledge of all these limitations must guide any practical application.

For the simulation procedure used, this empirical approach seems to give results in close agreement with those of the observed although they are more smoothed. This type of simulation naturally gives average motions and discards the earthquake specific features like high or low stress drop.

On the other hand, theoretical approaches require information about the source and propagation effects that at present it is very difficult to postulate. A promising method may be the use of empirical Green's functions combined with the similarity law of earthquakes. When small events are available and their focal mechanisms are similar to the target event, this method gives satisfactory results, Irikura[12].

Since the goal of the prediction is still far, a comprehensive study of all the results from various methods is the best approach for predicting strong ground motion for future large earthquakes.

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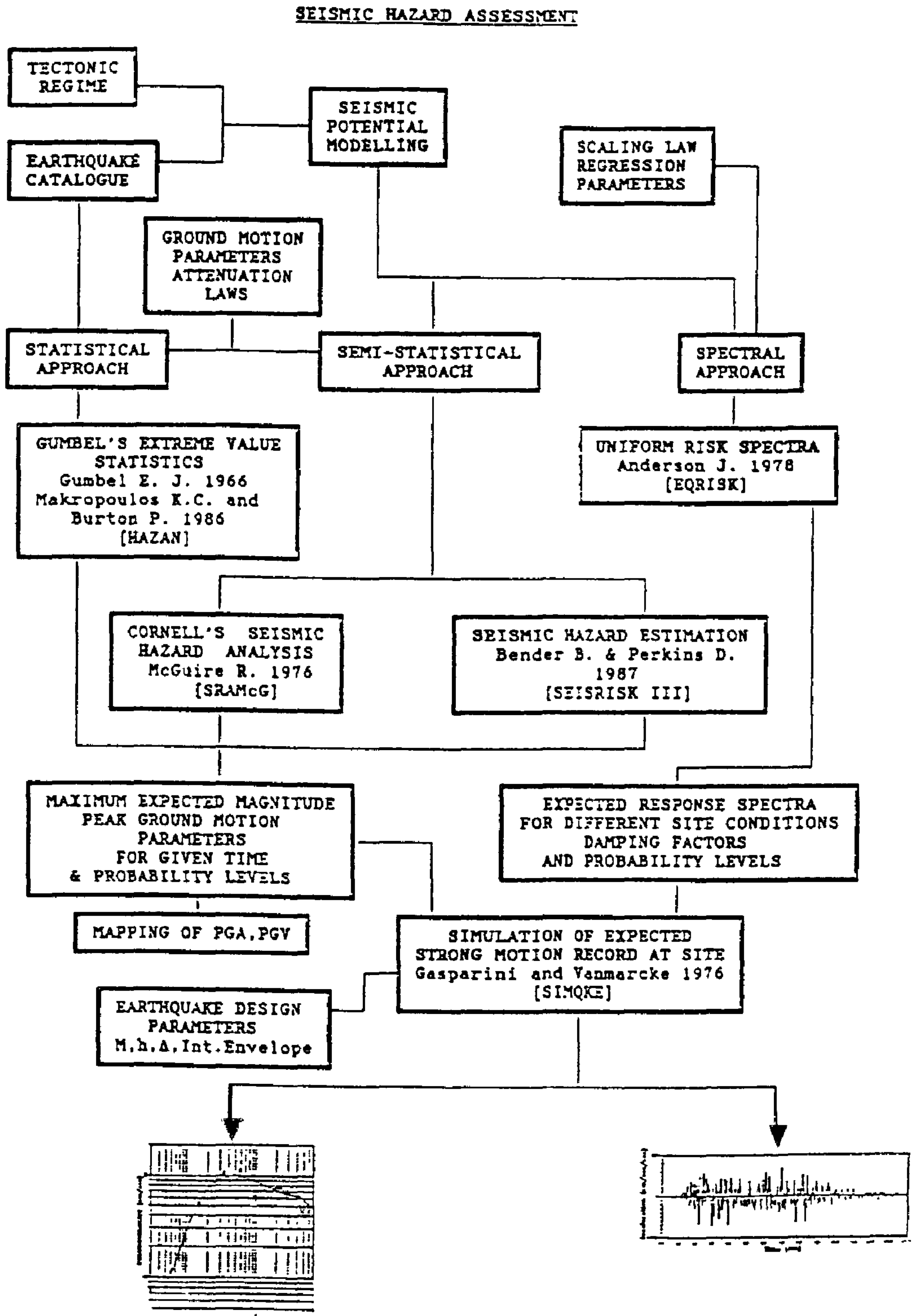


Figure 1. Flow-chart of the multi-methodological approach to seismic hazard assessment.

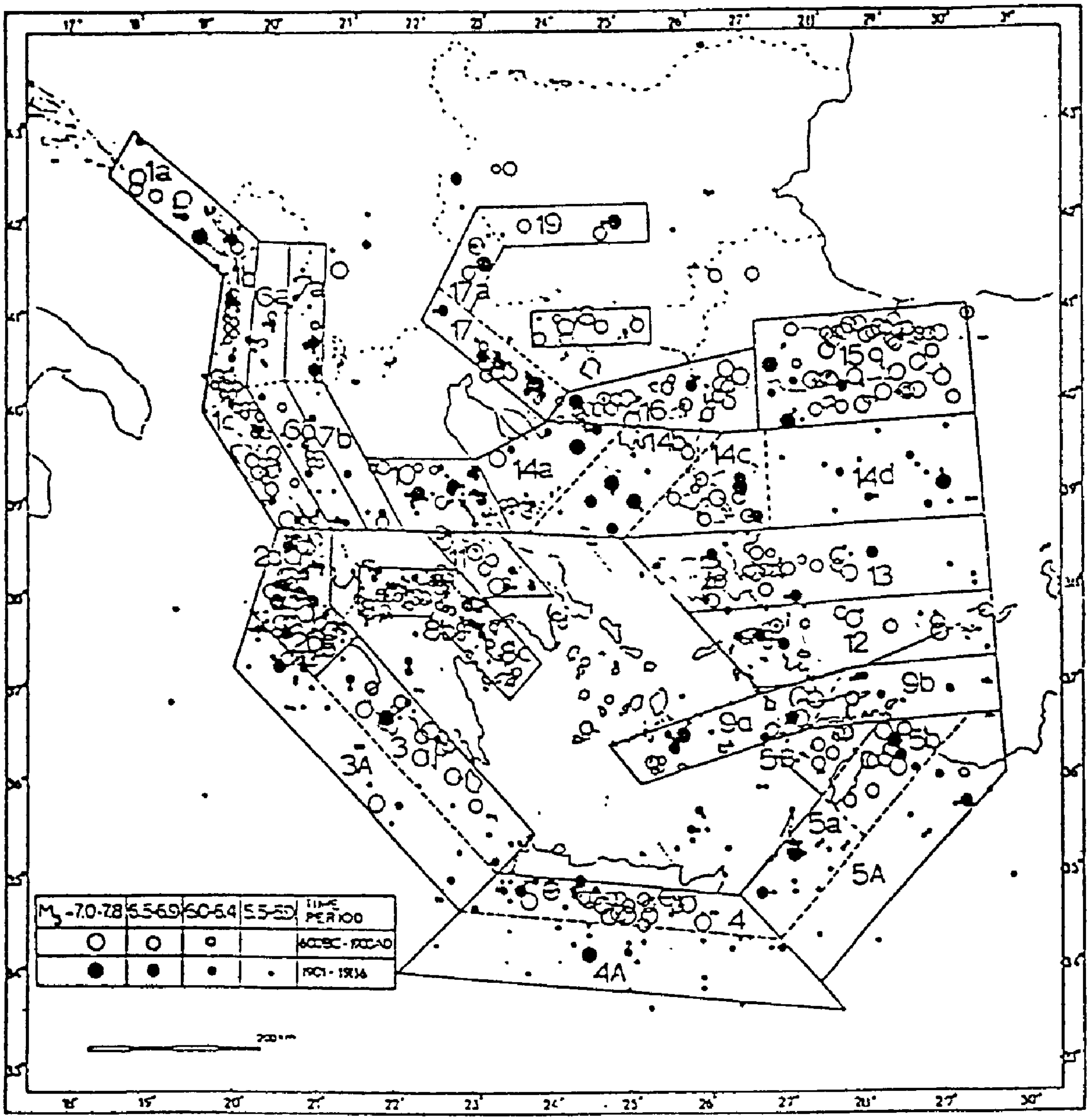


Figure 2. Source zone geometry after Papazachos, 1988.

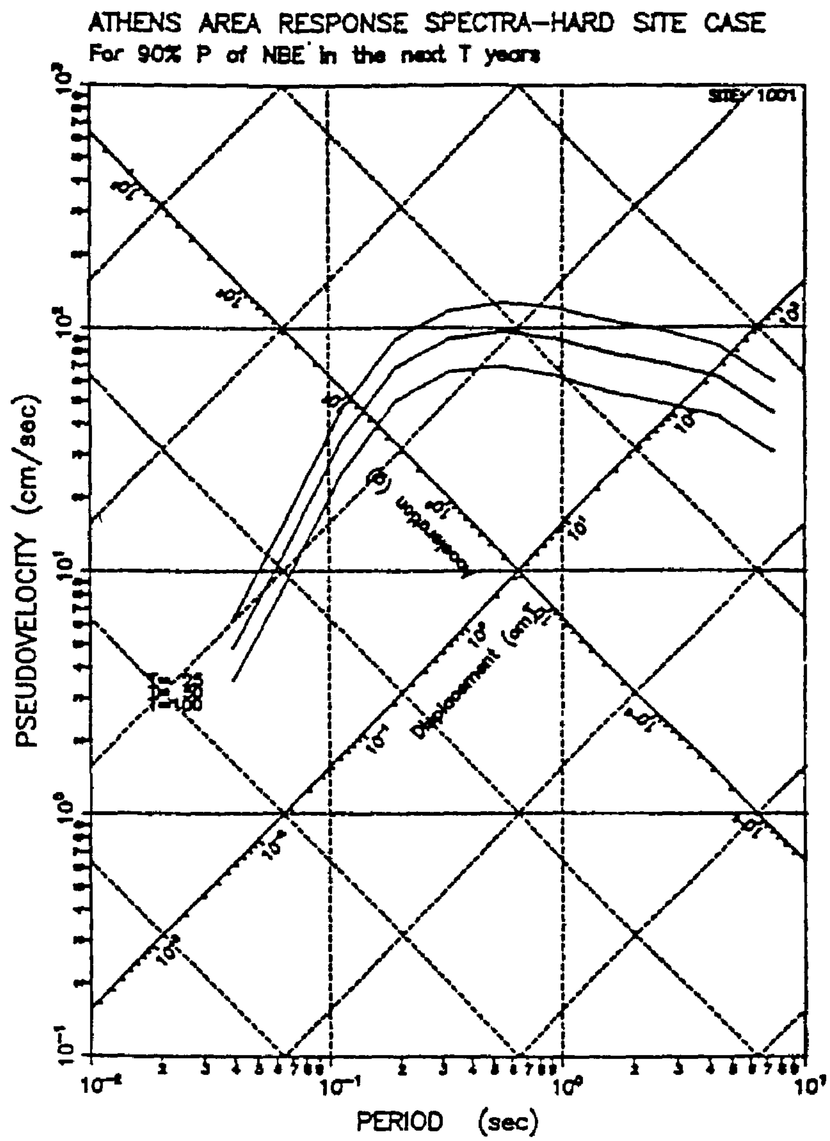
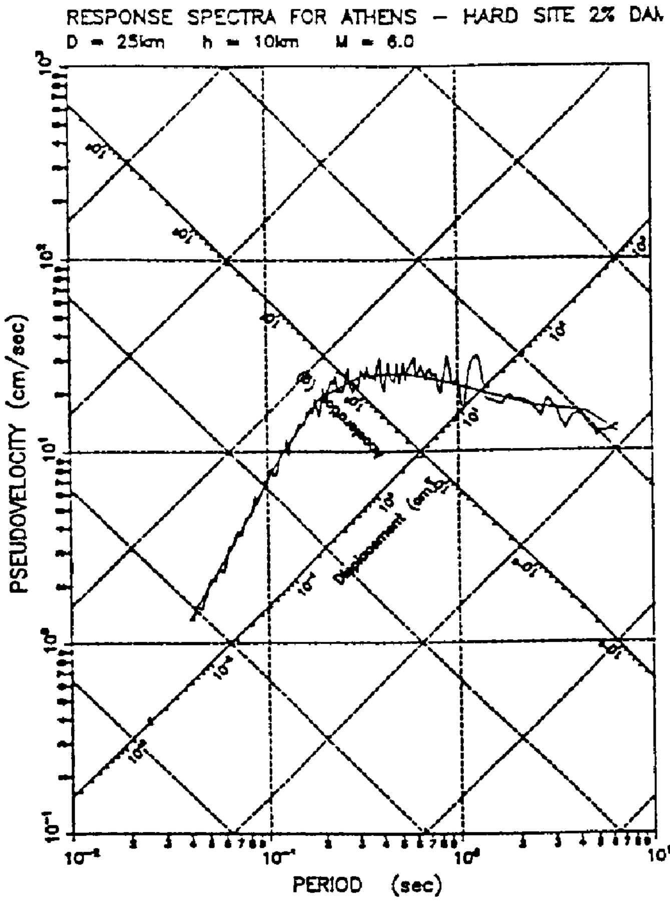


Figure 3. Expected response spectra for the Athens area with 90% probability of being the maxima in the next 25,50 and 100 years. Hard site case.



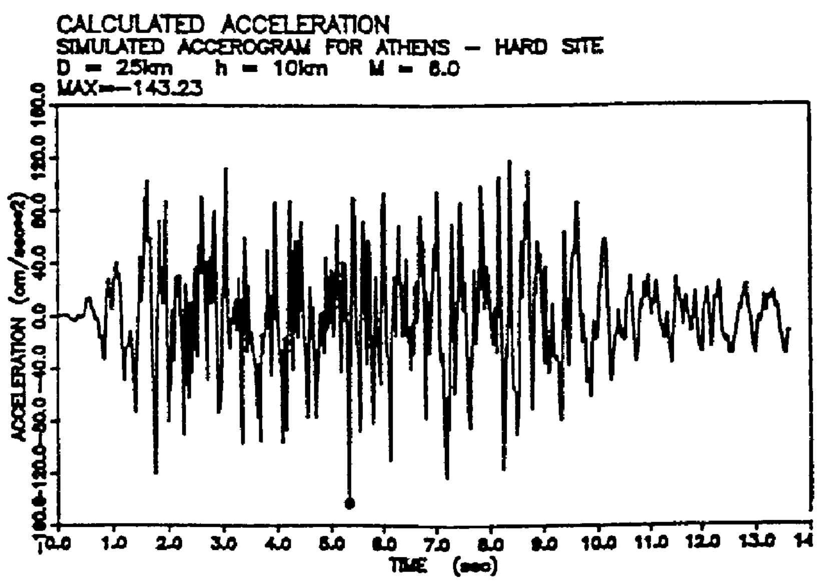


Figure 4. (a) Target and simulated response spectra, at Athens for an expected earthquake with M=6.0, D=25km and h=10km. (b) Simulated accelerogram for PGA=143.2 cm/sec^2.