SEISMICITY AND SEISMIC HAZARD FOR THE CITY OF FLORINA

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ABSTRACT

A study of the seismicity of the region of Florina as well as of the seismic hazard for the city of Florina are presented in this work. The seismicity in the area of Florina is studied, on the basis of historical and instrumental data. The data include also records of the local seismological station of Florina, which is in operation since November 1989. The seismic hazard for the city, is assessed in terms of macroseismic intensity, ground acceleration, ground velocity and spectral accelaration. It was found that the city is not affected by earthquakes of short epicentral distances, since strong shocks (M>5.5) are not generated within a distance of about 45 Km from the city, but it can be affected by very strong events generated at longer distances from the city of Florina. The time-predictable model for generation of shallow earthquakes in this area is also applied. The obtained results showed that an earthquake of a magnitude M=5.3 will occur in the area with a probability of 33% in the next 10 years, while this probability increases (76%) when the same magnitude is calculated for the next 20 years.

ΣΕΙΣΜΙΚΟΤΗΤΑ ΚΑΙ ΣΕΙΣΜΙΚΗ ΕΠΙΚΙΝΔΥΝΟΤΗΤΑ ΤΗΣ ΠΟΛΗΣ ΤΗΣ ΦΛΩΡΙΝΑΣ

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ΠΕΡΙΛΗΨΗ

Στην εργασία αυτή γίνεται λεπτομερής μελέτη της σεισμικότητας στην περιοχή της Φλώρινας και της σεισμικής επικινδυνότητας για την πόλη. Εξετάζεται η σεισμικότητα με βάση τόσο τους ιστορικούς σεισμούς όσο και τους σεισμούς του παρόντα αιώνα που έγιναν στον ευρύτερο χώρο της Φλώρινας. Μεταξύ αυτών είναι και τα δεδομένα που έχουν καταγραφεί από τον τοπικό σεισμολογικό σταθμό της Φλώρινας ο οποίος λειτουργεί από το Νοέμβριο του 1989. Γινεται επίσης εκτίμηση και της σεισμικής επικινδυνότητας της πόλης με βάση τη μακροσεισμική ένταση, την εδαφική επιτάχυνση και ταχύτητα και την φασματική επιτάχυνση. Βρέθηκε ότι η πόλη δεν απειλείται από σεισμούς κοντινών αποστάσεων, αφού δεν υπάρχουν εστίες ισχυρών (M>5.5) σεισμών μέχρι την απόσταση των 45 Km περίπου, εντούτοις ο κίνδυνος από

μακρινότερους ισχυρούς σεισμούς δεν είναι ανύπαρκτος. Το χρονικά εξαρτώμενο μοντέλο, για την γένεση επιφανειακών σεισμών, εφαρμόστηκε στην περιοχή. Τα αποτελέσματα έδειξαν ότι υπάρχει πιθανότητα 33% να γίνει σεισμός μεγέθους M=5.3 τα επόμενα 10 χρόνια στην περιοχή της Φλώρινας, ενώ η πιθανότητα αυξάνει (76%), για σεισμό ίδιου μεγέθους, για τα επόμενα 20 χρόνια.

INTRODUCTION

The area of Greece is seismically one of the most active regions of the world. The 2% of the mean annual global energy releases from this region (Tsapanos 1985). Greece has the highest seismicity in the western Eurasia. For this reason a large number of studies are referred to the seismicity of the area (Comninakis and Papazachos 1980, Papazachos 1980, Hatzidimitriou 1984, Hatzidimitriou et al. 1985, Tsapanos 1988, Papazachos 1989, 1990). We considered the seismicity as an increasing function of the earthquake magnitudes as well as of the number of the earthquakes which occurred in a region during a certain time span.

The term of seismic hazard defines the probability of the occurrence of a given earthquake magnitude or a macroseismic intensity or a ground acceleration, velocity in a region during a certain time period. The seismic hazard based on the prereferred parameters has been determined for the area of Greece by many seismologists (Makropoulos and Burton, 1985; Papaioannou, 1984, 1986; Stavrakakis, 1985; Papazachos et al., 1990, 1992).

Based on the most reliable and accurate data, the seismicity of the broader area of the city of Florina is determined in the present work. The seismic hazard of the city of Florina (40.78°N-21.40°E) is evaluated on the basis of the macroseismic intensity, the ground acceleration, velocity, and the spectral accelaration.

THE GEOTECTONICS OF THE AREA

The region of Florina is a part of the broader Neogene-Quaternary basin of Monastiri-Florina-Ptolemaida-Kozani. This intra mountain basin created in a NNW-SSE direction along the oreographic axis of Hellenides. The basement (bed-rock) of the area belongs to the north Pelagonian geological zone, which consists of Palaeozoic metamorphic rock and the Mesozoic carbonate cover. Younger subbasin, trending NE-SW, developed almost perpendicular to the main basin. A post-middle Miocene age could be considered as the most acceptable one for the initial creation of the Florina and Ptolemaida basins (Pavlides, 1985). Two extensional phases have been detected in the areas after a quantitative neotectonic analysis (Pavlides and Mountrakis, 1987) a late Miocene-Pliocene one with a NE-SW average direction of extension and a recent Pleistocene one with a NW-SE direction of extension.

EXPERIMENTAL SETTING

Three sources of data were used for the compilation of a catalogue which forms the data set of the present study: 1) the catalogue of Comninakis and Papazachos (1986), 2) the monthly bulletins of the Geophysical Laboratory of the University of Thessaloniki and of the National Observatory of Athens and 3) the catalogue of Papazachos and Papazachou (1989).

It is well known that critical problems involved in the seismicity studies are the accuracy, the homogeneity and the completeness of earthquake data. Discussions on the accuracy and homogeneity can be found in particular catalogues. In order to determine the completeness of data, a procedure based on the linearity of the cumulative number of main shocks versus time is applied (Papazachos, 1980). The data are complete for the following magnitude (M_L is adopted) ranges and the corresponding time periods:

$M_L \geq 5.5$	1858-1991
$M_L \geq 5.0$	1905-1991
$M_L \geq 4.5$	1911-1991
$M_L \geq 4.0$	1964-1991
$M_L \geq 3.5$	1982-1991

In figure (1) the plot of the cumulative number of main shocks, N, for these five magnitude ranges is demonstrated.

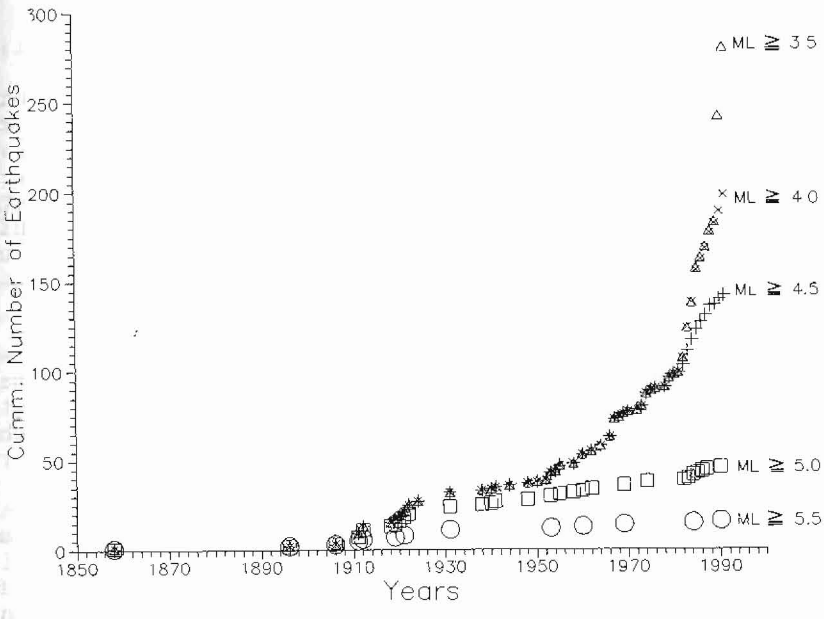

Fig.1. Plot of the cumulative number of main shocks N versus time for five magnitude ranges

THE SEISMICITY OF THE AREA

The area is generally characterized by low seismicity, and the strongest earthquake during the present century occurred in February 18, 1911 with M_s=6.7 (Comninakis and Papazachos, 1986; Papazachos and Papazachou, 1989) in the SE part of Ochrid lake.

The spatial distribution of the epicentres of all the shocks referred in the catalogue is given in figure (2). Although the epicenters are spreaded almost all over the area, there are areas characterized by major or minor activity. The majority of the epicenters is located in the Greece-Albania-Yugoslavia borders, in the Epirus region and in the area of Goumenissa, where the recent strong (M_s=6.0) earthquake of 21st of December 1990 occurred (Panagiotopoulos et al., 1993). All the earthquakes generated in the region are shallow ones, and the seismogenic layer has a depth of about 10 Km.

Following the fact that the epicenters of earthquakes, with $M_L \geq 3.0$ occurred in the region, show a tendency of clustering at particular areas (fig. 2), an attempt was made to examine the seismicity in terms of the areal distribution of the values of the parameter, a, of the Gutenberg-Richter relation using ÿ catalogue constructed for the present study (covered time span 1858-1992). All the examined area was covered by grid of points with 0.2 degrees spacing. Around each knot of the grid, all the shocks within a circle with radius R=20Km were considered. Then using the predetermined value of the parameter b (=0.80) which is valid for the area (Papazachos, 1990), the parameter a_k of the relation:

$$a_k = \log N + bM \qquad (1)$$

normalized to one year, a, was calculated in terms of a computer program compiled by Hatzidimitriou (1984). The values of the parameter a were plotted and contours were drawn with interval 0.2, using the SURFER PC-computer package by the application of the "inverse distance" method. The map of figure (3) illustrates the results, obtained, for the area. Three clusters of high seismic activity can be distinguished. The two of them, south of Ochris-Prespa lakes, are associated with the shocks within a source with M_{max}=6.5 (Papazachos, 1990), while the third one is related to the December 21, 1990 Goumenissa earthquake.

The recent experience of the last 10 years from the seismic activity in Greece show that even moderate (M_s=5.5 ± 0.3) magnitude earthquakes may cause considerable damage to populated centers. Moreover recent research efforts lead to a reliable time- and magnitude - predictable model for the earthquake prediction (Papazachos and Papaioannou, 1993). For this reason we consider all the earthquakes located at northwestern Macedonia (Florina and surroundings), which do not belong to any seismic source of strong earthquakes. The constant a of the relation (1) was determined from the present century data and was found equal to a=3.57. The strongest known earthquake (M≈6.0) in this area occurred in 896 AD and caused damage (I_{MM}=VIII) to Veria (Papazachos and Papazachou, 1989). Using the moment of this earthquake and the values of the parameters a and b the moment rate, M_o, of this area was found equal to $3.72 \cdot 10^{23}$ dyn*cm/yr. Using this value of the moment rate as input in the formula proposed by Papazachos and Papaioannou (1993) in their time- and magnitude- predictable model, we found that for the next 10 and 20 years time window a magnitude 5.3 earthquake has probability of occurrence 33% and 76% respectively, given that 6 years passed since the last earthquake with magnitude 5.4 on January 7, 1987.

SEISMIC HAZARD OF THE AREA

The probabilistic assessment of seismic hazard at a particular site is defined as the estimation (with a certain degree of uncertainty) of the exceedance probability of a given seismic intensity (macroseismic intensity, peak ground values or their spectral values) within a given time period. The output of such seismic hazard assessment can be used in the seismic design of the constructions. An extended review of the seismic hazard methods applied in Greece can be found in Makropoulos et al., (1993).

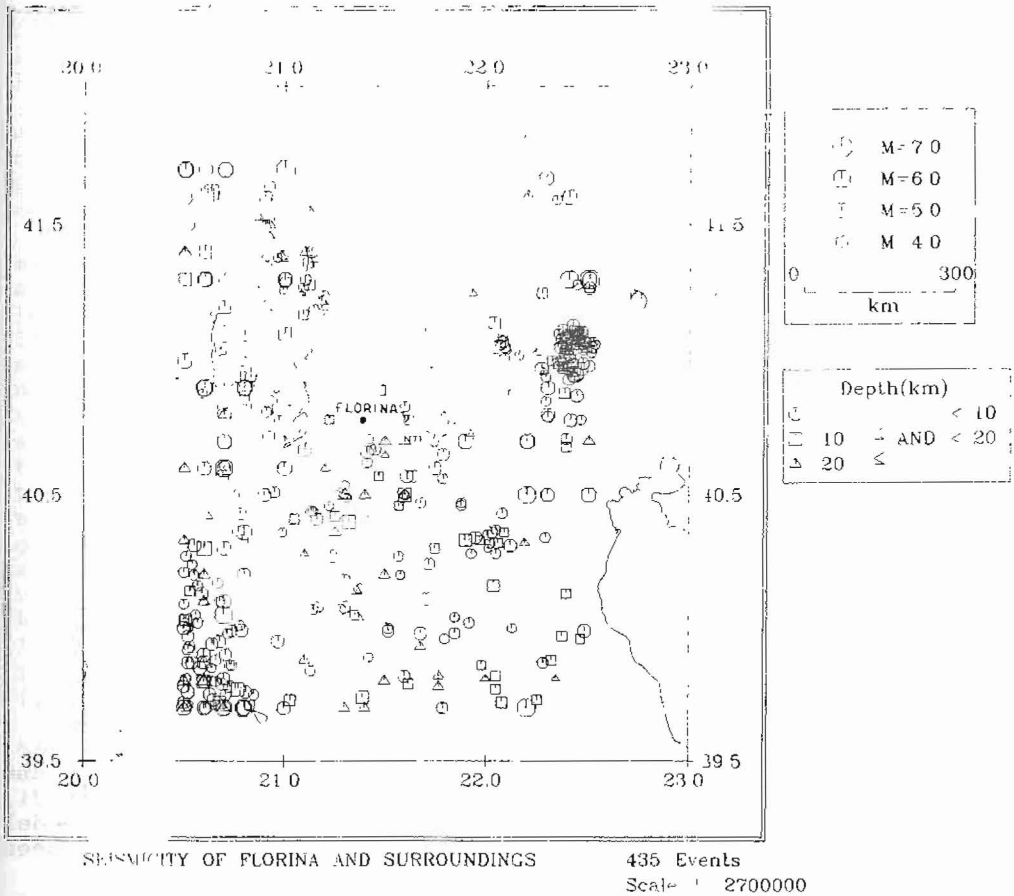

Fig.2. Spatial distribution of the epicenters of earthquakes occurred in Florina and surrounding area.

Seismicity of Florina (NW Macedonia) area

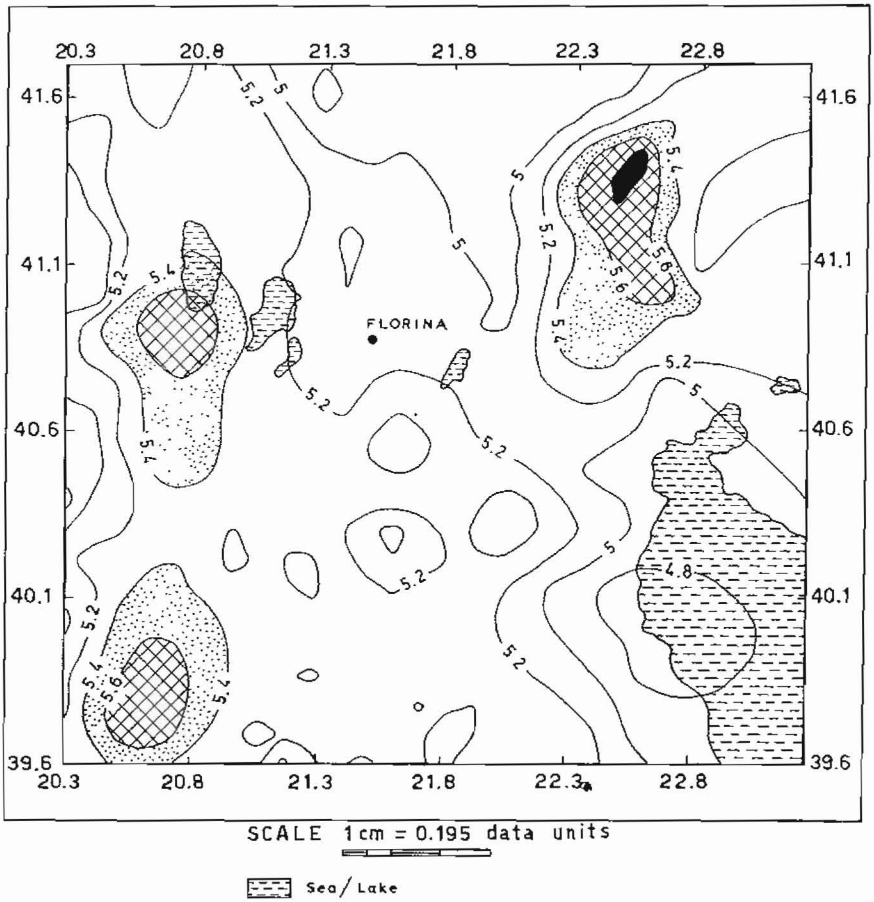

Fig.3. Seismicity of Florina and surrounding area.

A realistic approach of the anisotropic radiation of the strong motion in near field has been proposed by Papazachos C., (1992). The elliptical shape of the anisotropic radiation model was adopted by the same study. Thus the next equation has been proposed (Papazachos C., 1992):

$$I_o(\varphi) = I_{o\,min} + (v/2)*\log(S) \qquad (2)$$

where $I_o(\varphi)$ is the azimuthal variation of intensity in the epicenter, φ is the azimuth of the main axis of elliptical model, I_{omin} is the the $I_o(\varphi)$ along the minor axis of the elliptical anisotropic radiation model, v is the geometrical spreading factor (with average value for Greece v=-3.39), S is a function of the ellipticity of the isoseismal, the azimuth of the major axis of the isoseismal and the azimuth of the source-site path. In the present study we examine the seismic hazard using the McGuire's (1976) EQRISK computer program as it was modified (Margaris, pers. comm.) after incorporating the equation (2).

The seismic source model used is the one proposed by Papazachos C., (1992) and the seismic hazard was examined for the macroseismic intensity, peak ground acceleration and velocity. The attenuation relations used are those proposed by Margaris and Papazachos (1992) (for the macroseismic intensity, I_{MM}) and by Theodulidis (1991) (for the peak horizontal acceleration, a_g and velocity, v_g), which are:

$$I_{MM} = 2.90 + 1.61M_s - 1.69\ln(R+16) \quad (3)$$
$$\ln a_g = 3.88 + 1.12M_s - 1.65\ln(R+15) + 0.41S + 0.70P \quad (4)$$
$$\ln v_g = -0.79 + 1.41M_s - 1.62\ln(R+10) - 0.22S + 0.80P \quad (5)$$

where M_s is the surface wave magnitude, R is the epicentral distance, S is the soil conditions parameter (S=0 for "alluvium" and S=1 for "rock") and P is a binary parameter with value either equal to 0 (mean attenuation) or equal to 1 (mean+1σ).

For the macroseismic intensity we used both the relation (3) as a mean attenuation formula for all the sources (circle model) affecting the city as well as incorporating anisotropic radiation (elliptical model) of the strong motion (Margaris and Papazachos, 1991). The graph in figure (4a) shows the macroseismic intensity, I_{MM}, as a function of the mean return period, T_M, assuming no effect of the anisotropic radiation (dashed line) and considering the anisotropic radiation (continuous line). It can be seen that the results obtained using the first model are higher than those obtained from the second one. This is due to the fact that in the case of the second model the city is located at a site which is at the direction of the highest attenuation gradient (minor axis of the ellipsis). The graphs in figures (4b) and (4c) show the horizontal peak ground acceleration and velocity respectively as a function of the mean return period. According to the new greek seismic code the city of Florina is located at the first zone of seismic hazard in Greece. The dashed line in figure (4b) shows the seismic hazard curve ($\ln a_g$ vs T_m) for this zone of seismic hazard.

Papazachos et al. (1990) found that the results from the hazard analysis, i.e. any of the seismic hazard parameters, SI, versus the mean return period for $T_M \leq 1000$ yrs can be fitted by a log-linear equation of the type:

$$SI = B_1 + B_2 * \log T_M \quad (6)$$

The constants B_1 and B_2 for the peak ground acceleration ($\ln a_g$) were found equal to 2.68 and 0.78 respectively.

Theodulidis (1991) developed a method for the estimation of the probabilistic response spectra. Following this method and considering anisotropic radiation of the attenuation of the spectral values, we calculated the probabilistic response spectra for the city of Florina. The type of the proposed attenuation

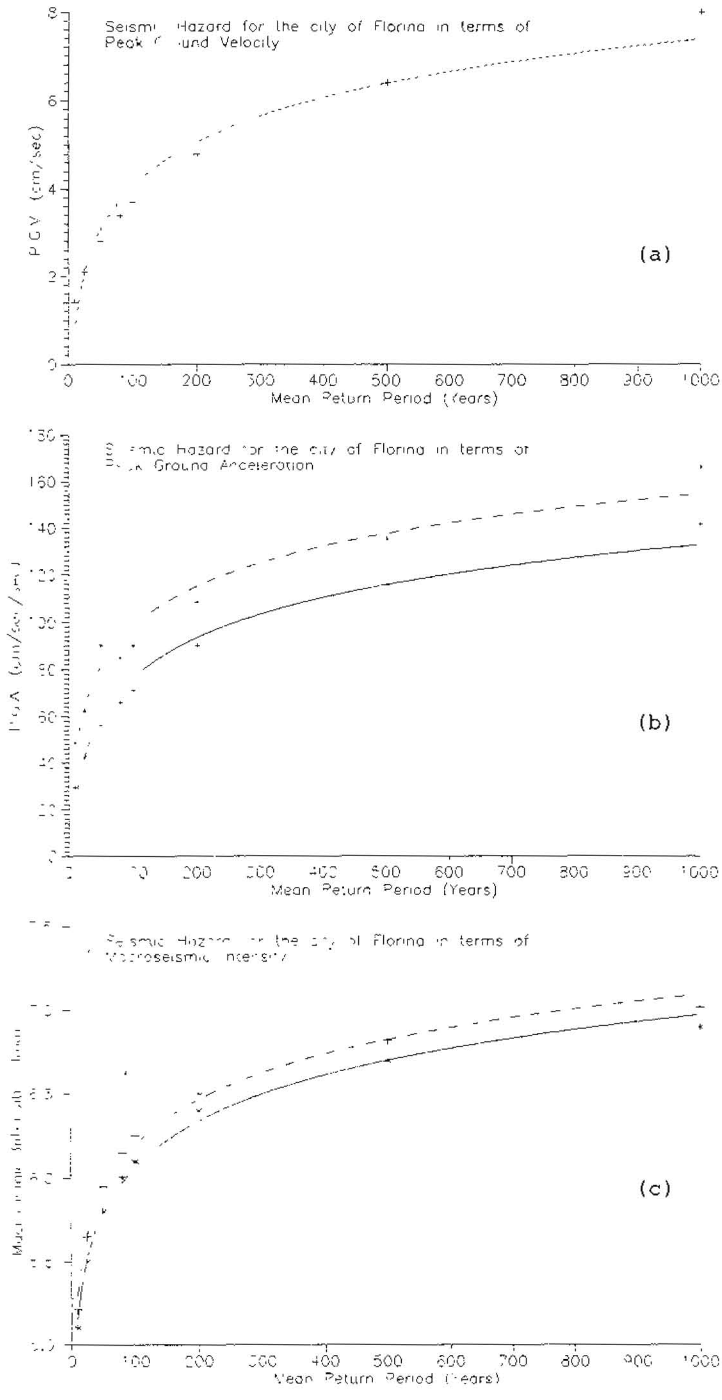

Fig.4. Seismic hazard for the city of Florina in terms of: a) peak ground velocity, b) peak ground acceleration and c) macroseismic intencity.

formula of the spectral values is similar to the formula (4). We determined the probabilistic response spectra (pseudo-acceleration, S_a, versus T) for the city of Florina by considering "intermediate soil conditions" (S=0.5) for two mean return periods (T_M=50 and 475 years). These two probabilistic response spectra are shown in figure (5).

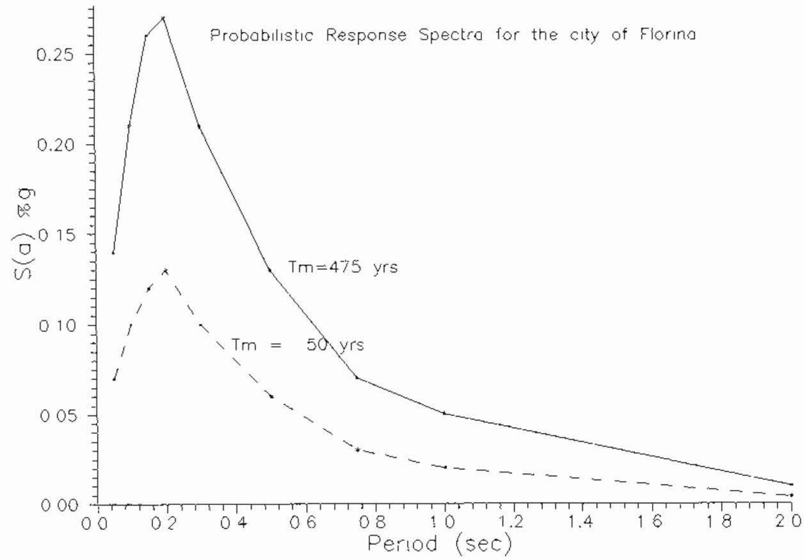

Fig.5. Plot of the probabilistic response spectra for the city of Florina.

REFERENCES

Comninakis,P.E. and Papazachos,B.C., (1980). Space and time distribution of the intermediate depth earthquakes in the Hellenic arc. Tectonophysics, 70, 33-47.

Comninakis,P.E., and Papazachos,B.C., (1986). A catalogue of earthquakes in Greece and the surrounding area for the period 1901-1985. Publ. Geoph. Lab., University of Thessaloniki, 1, 167pp.

Hatzidimitriou,P.M., (1984).Seismogenic volumes and seismic sources of the Aegean and surrounding areas. Ph.D. Thesis, University of Thessaloniki, Thessaloniki, 162pp. (in Greek).

Hatzidimitriou,P.M., Papadimitriou,E.E., Mountrakis,D.M. and Papazachos,B.C., (1985). The seismic parameter b of the frequency magnitude relation and its association with geological zones of Greece. Tectonophysics, 120, 141-151.

Makropoulos,K.C. and Burton,P.W., (1985). Seismic hazard in Greece. II.Ground acceleration. Tectonophysics, 117, 259-294.

Makropoulos,K.C., Theodulidis,N.P., Margaris,V.N. and Voulgaris,N., (1993). Seismic hazard in Greece: Review of results and perspectives,. Proc. of the 2nd Congress of the H.G.U., Florina 5-7 May 1993, (this volume).
McGuire,R.K., (1976). FORTRAN computer program for seismic risk analysis, U.S. Geolo. Surv., Open file rep. No 76-67.
Margaris,V.N. and Papazachos,B.C., (1991). Azimuthal dependent attenuation in the Southern Balkan region. Internal report of ITSAK, 1991/3, 36pp.
Panagiotopoulos,D.G., Papadimitriou,E.E., Papaioannou,Ch.A., Scordilis,E.M. and Papazachos,B.C., (1993). Source properties of the December 21, 1990, M_s=6.0 Goumenissa earthquake in Northern Greece. Proc. of the 2nd Congress of the H.G.U., Florina 5-7 May 1993, (this volume).
Papaioannou,Ch.A., (1984). Attenuation of seismic intensities and seismic hazard in Greece and surrounding area. Ph. D. Thesis, University of Thessaloniki, Thessaloniki, 200pp. (in Greek).
Papaioannou,Ch.A., (1986). Seismic hazard assessment and long term earthquake prediction in Southern Balkan region. Proc. 2nd Int. Sem. on Earthq. Progn., Berlin, 223-241.
Papazachos,B.C., (1980). Seismicity rates and long term earthquake prediction in Aegean area. Quatern. Geod., 3, 171-190.
Papazachos,B.C., (1989). The seismic zones in the Aegean and surrounding area. Proc. Europ. Seism. Com. XXI Gener. Assembly, 23-27 August Sofia 1988, 82-87.
Papazachos,B.C., (1990). Seismicity of the Aegean and surrounding area. Tectonophysics, 178, 287-308.
Papazachos,B.C., (1992). A time and magnitude predictable model for generation of shallow earthquakes in the Aegean area, Pageoph, 138, 287-308.
Papazachos,C.B., (1992). Anisotropic radiation modelling of macroseismic intensities for estimation of the attenuation structure of the upper crust in Greece, Pageoph, 138, 445-469.
Papazachos,B.C. and Papazachou,K., (1989). The earthquakes of Greece. Ziti Publications, Thessaloniki, 356pp.
Papazachos,B.C. and Papaioannou,Ch.A., (1993). Long term earthquake prediction in the Aegean area based on a time and magnitude predictable model. Proc. of the 2nd Congress of the H.G.U., Florina 5-7 May 1993, (this volume).
Papazachos,B.C., Papaioannou,Ch.A., Papastamatiou,D.J., Margaris,B.N. and Theodulidis,N.P., (1990). On the reliability of different methods of seismic hazard assessment in Greece. Natural hazards, 3, 141-151.
Papazachos,B.C., Papaioannou,Ch.A., Margaris,B.N. and Theodoulidis,N.P., (1992). Regionalization of seismic hazard in Greece based on seismic sources. Natural hazards, (in press).
Pavlides,S.B., (1985). Neotectonic evolution of the Florina-Vegoritis-Ptolemais basins (W. Macedonia, Greece). Ph. D. Thesis, University of Thessaloniki, 265pp. (in Greek).
Pavlides,S.B. and Mountrakis,D.M., (1987). Extensional tectonics of northwestern Macedonia, Greece, since the late Miocene. Journ. Struct. Geology, 9, 385-392.

Stavrakakis,G.N., (1985). Contribution of Bayesian statistics to the seismic hazard evaluation in and around of Crete island: Simulation of strong ground motion. Ph. D. Thesis, University of Athens, Athens, 294pp. (in Greek).

Theodulidis,N.P., (1991). A contribution to the study of strong ground motion in Greece, Ph.D. Thesis, University of Thessaloniki, 500pp,

Tsapanos,T.M., (1985). A contribution to the study of the seismicity of the Earth. Ph.D. Thesis, University of Thessaloniki, Thessaloniki, 147pp. (in Greek).

Tsapanos,T.M., (1988). The seismicity of Greece in comparison with the seismicity of other seismogenic countries of the world. Proc. of the First Symb. on Recent Trends in Seismology and Geophysics of the Greece and Surrounding Areas, Thessaloniki 1-3 July 1988, 186-193.