A PRELIMINARY PROBABILISTIC ASSESSMENT OF THE SEISMIC HAZARD IN TURKEY

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SUMMARY

This paper provides a preliminary estimate of the relative hazard in Turkey in terms of the probabilistic estimates of the maximum MSK intensity and maximum horizontal peak ground acceleration for given return periods. It is mainly based on the macro-seismic and instrumental seismic data of the last 70 years, out of which only the last 15 years can be assumed to be moderately complete, and the neo-tectonic maps of Turkey. The geo-tectonic data is employed in the delineation of seismic sources and, to some extent, in the assesment of maximum magnitudes. The difficulty in correlating the known seismicity with geologic evidences of neo-tectonic activity in many areas may bear on the problem of seismic source identification. For the intensity attenuation relationships the iso-seismal maps of Turkish earthquakes are utilized. A relationship for the attenuation of the acceleration based on the California data is adopted from the literature.

There is much need to improve the method of approach, and to refine the seismic regionalization and the attenuation relationships so that more rational and consistent estimates of the seismic hazard can be made.Comments on these issues are invited to help guide the future research and revisions of the accompanying maps.

INTRODUCTION AND BACKGROUND

Turkey has suffered great damages due to many destructive earthquakes in the past. The probability that the next major earthquake will be destructive is ever increasing because of the rapid population growth and economic developments. In order to ensure that adequate and optimal seismic safety requirements are met in buildings and engineering structures, it has become an important task for the authorities to assess the seismic hazard in probalistic terms in each part of the country.

The first official seismic hazard map of 1945 distinguishes the zones of heavy, likely and no earthquake damage based on the available macro-seismic and neo-tectonic data. Studies conducted by Ketin (1948, 1966, 1968), Lahn (1949), Pınar and Lahn (1952), Omote and İpek (1959), İpek et, al. (1965), Ergin et, al. (1967), Karnik (1968, 1971), Tabban (1970), Ambraseys (1971) and Mc Kenzie (1972) have greatly contributed to the improvement of the seismic and tectonic data base utilized in for the preparation of the current, 1972 version of the seismic hazard map. This map distinguishes four hazard zones on the basis of maximum expected intensities (Ergünay, 1976).

It has recently been a matter of concern that these maps ignore the role that earthquake occurrence rates have on the hazard since the zones are rated equally on the basis of maximum intensites ever experienced regardless the associated return periods. Apart from the numerous studies of local or regional scale, studies of Alsan (1972), Gencoğlu and Tabban (1973), Üçer et. al. (1977) Bath (1979) and Hattori (1979) have addressed the problem of assessment of the seismic hazard in Turkey through statistical means.

METHODOLOGY

Estimation of the relative seismic hazard in probabilistic terms involve the following major distinct considerations:

- Seismic regionalization, i.e. the delineation of the seismic source areas.
- Analysis of the statistical characteristics of the historical earthquake occurrences in each source.
- Determination of the maximum earthquake occurrence potential in each source.

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- Assessment of the attenuation characteristics of the ground motion resulting from earthquakes of each source.
- Utilization of a probabilistic model for calculation of the extreme cumulative probability of the site intensity or accelaration for given return periods.

These items are addressed under the following headings.

DELINEATION OF THE SEISMIC SOURCES

One of the biggest problems faced in the preparation of the earthquake hazard maps is the delineation of the seismic sources and the assessment of the associated maximum earthquake potentials. Solution of this problem entails the full utilization of the geologic, tectonic, paleo-seismologic data, the historical macro and instrumental seismic records and micro-earthquake survey results. Yet, the state-of-the-art today does not allow for a standard general practice and the methodologies employed in delineation of the seismic sources and assessment of maximum earthquake potentials are quite subjective in nature. It is possible for different researchers to come up with different seismic source delineations using the same data base.

The general criterion adopted in the seismic regionalization procedure is that the spatial and temporal characteristics of the future earthquakes will follow the same general characteristics of the past earthquakes as indicated by the historical data. The seismic sources are delineated on the basis of the uniformity of the geo-tectonic features and the consistency of the earthquake mechanism and the attenuation characteristics. The tentative seismic sources considered in this study is shown in Figure 1. In the determination of source boundaries the macroseismic locations and the isoseismal maps of large earthquakes and the known Quaternary faulting as indicated by the tectonic maps prepared by the Mineral Research and Exploration Institute of Turkey are employed.

The logic of the seismic source delineation reflects the concepts of the plate tectonics model developed by Mc Kenzie (1972). According to this model the occurrence of earthquakes in Turkey are due to the relative motion of the three major (Africa, Eurasia and Arabia) and the three minor (Aegeon, Turkish, and Black Sea) plates. The Turkish plate, which covers most of Turkey, Cyprus and the intervening sea is considered to be moving southwestward towards the Aegean Plate. The Turkish plate is bounded at the North by the North Anatolian Fault (Source No. 2) between the triple junctions as described by Mc Kenzie (1972) and, at the south by the East Anatolian Fault, the South Anatolian Thrust Front (Source No. 4) and the Cyprus Thrust Zone (Source No. 11). Source No. 3 convers most of the speculated Northeastern extension of the North Anatolian Fault towards the Caucausus and is considered as an areal source since the scattered epicentral distribution does not allow any correlation with the lineaments. The predominantly strike-slip character of faulting associated with the Sources 2 and 4 becomes predominantly normal to the west of the 30°E meridian as indicated by Mc Kenzie (1972). The seismic sources of the Aegean minor plate are closely associated with the local tectonic features. Source No. 1 encompasses the Marmara Graben, Gemlik-İznik and Yenice-Gönen Faults. Faults around the Gulf of Edremit, Simav-Bakırçay Faults, Gediz, Küçük Menderes, Büyük Menderes Grabens are included respectively in the sources numbered 5,6 and 7. Source No. 9 is the eastern extension of the Pliny-Strabo trench associated with the overthrusting of the Aegean plate towards the Mediterranean floor. The earthquakes associated with the Gulf of Kerme and Elmalı-Korkuteli-Bucak Thrust zone are included in source No. 8. In the sources numbered 2' and 4' the same seismic activity density of the seismic sources 2 and 4 are used. Different maximum earthquake magnitudes are selected for sources 2' and 4' than those correspond respectively to sources 2 and 4 owing to to their different earthquake mechanisms and dimensional characteristics.

The isolated earthquakes in Central Anatolia between the two main Alpine fold belts are treated as the seismic background. It was assumed that these earthquakes could occur over broad areas not otherwise incuded in the seismic sources.

RECURRENCE RELATIONSHIPS

The empirical recurrence relation of Gutenberg and Riather (1958).

$$\log N = a + bM,$$

where N is the number of earthquakes equal to and above magnitude M in a given seismic source and a given period, and a and b are regression constants, has been extensively used in many seismicity studies.

The earthquake records are compiled from Ergin et al. (1967), Alsan et al. (1975) and supplemented by NOAA data for the recent years. Unfortunately the in completeness and nonhomogeneity of this data prohibits its direct application, for regression analysis. These adverse qualities stem mainly from the deficiency of data in small magnitudes in earlier reporting periods and exhibits itself in unrealistically low b values as obtained from raw data. Therefore to arrive at realistic assessments of the recurrence relationships one has to combine a short sample of events which is complete in small events with a longer sample which is complete in large earthquakes. This can be achieved by creating and artificially homogenous data set through determination of the period over which the data in a given magnitude group is completely reported (Stepp, 1972). The regression constants a and b are obtained by applying a least-square analysis on the adjusted data set for each seismic source.

For all the seismic sources the value of a varies between 3 and 5 and the value of b varies between -0.60 and -0.97.

MAXIMUM MAGNITUDES

The determination of the maximum magnutude for a source zone is a difficult and quite subjective problem. In seismic sources with prominent faults and large activity the maximum magnitudes can be determined through applications of magnitude versus fault rupture regression equations or (e.g. Slemmons, 1978) on the basis of historical maximum magnitudes. The standard rule-of-the-thumb practice is to assume one half of the total fault length as the rupture that will correspond to the maximum magnutude or increse the maximum historical earthquake magnitude by half a magnitude unit to yield the maximum magnitude. Both of these approaches may not necessarily yield coherent maximum magnitude estimations among the seismic sources.

In the methodology used herein the former procedure is utilized to determine maximum magnitudes associated with seismic sources encompassing major faults and the latter procedure is applied to seismic sources where the tectonics is very complex or where it is not possible to single out a prominent fault. In each case it has also been insured that the maximum magnitudes are in good conformity with the annual N = 0.001 intercept magnitude of the corresponding recurrence relationship. The assigned maximum magnitudes vary from 8.0 (Source No. 2) to 6.5 for the background seismicity.

ATTENUATION RELATIONSHIPS

The scarcity of the strong-motion acceleration data in Turkey makes it indispensible to define the attenuation on the basis of intensities for a rational seismic risk assessment. The site intensity resulting from a given earthquake can be assumed to be expressed by an attenuation equation of the form (e.g. Howell and Schultz, 1975):

$$I = I_o + c_1 + c_2 \ln(R + c_3) \qquad (3)$$

where I is the site intensity at an epicentral distance R, I_o is the maximum epicentral intensity and C s are regression constants. The relationship between the maximum intensity, I_o, and the magnitude, M, has been computed in the following form for many parts of the world.

$$M = c_4 + c_5 I_o \qquad (4)$$

The form of the attenuation relationship adopted in this study is obtained through combination of Eqns. 3 and 4 to yield:

$$I = c_6 + c_7 M + c_2 \ln (R + c_3) + \varepsilon \qquad (5)$$

where the random error term, ε, with zero mean and a standard deviation of σ is included.

The data base for determination of this equation consists of the isoseismal maps of large earthquakes associated with the seismic sources. For elliptical isoseismals associated with strike-slip faulting the epicentral distance, R, is interpreted in the direction both perpendicular and parallel to the fault axis and the respective attenuation relationships are determined. The so-called average attenuation relationship is then obtained through averaging of these two relationships. This relationship roughly corresponds to that obtained on the basis of the radius of the circle having the same area encompassed by the corresponding iso-seismal contour.

The average attenuation relationships have been obtained for each seismic source zone and then combined to yield an overall intensity attenuation relationship for Turkey given by:

$$I = -2.72 + 2.12\ M - 1.38\ \ln\ (R + 7) \qquad (6)$$

with a standard deviation of $\sigma = 0.7$ in intensity units.

For quaintification of the seismic hazard in peak ground acceleration one can either use the relationships between the site intensity and the peak ground acceleration or resort to attenuation relationships that can provide the peak ground acceleration as a function of the hypo-or epicentral distance, magnitude and site conditions. In this paper, for illustrative purposes, the seismic hazard assessments are also provided based on the acceleration attenuation relationship of Mc Guire (1978). For rock (hard soil) sites this relationship provides the peak ground acceleration, a_g, in gals, in terms of the hypocentral distance, R, in km's, as follows:

$$\ln a_g = 3.40 + 0.89\ M - 1.17\ \ln R \ ; \ \sigma_{\ln a_g} = 0.62 \qquad (7)$$

It should be noted that the Eqn. 7 is based on the local magnutudes whereas most of the reported magnutudes for Turkish Earthquakes are surface wave magnitudes. Considerable differences might exist between the two magnitude definitions especially in higher magnutude levels.

PROBABILISTIC SEISMIC RISK MODEL

The seismic risk analysis model employed in this study is mainly based on the works of Cornell (1968, 1971) and can be represented by the "total probability theorem" (Mc Guire, 1976):

$$P[A] = \iint P[\,A\,]\ s \text{ and } r]\ \ f_S(s)\ f_R(r)\ ds\ dr \qquad (1)$$

Here A represents the event that a specific value of ground-motion intensity (e.g. intensity or peak ground acceleration) is exceeded at the site during an earthquake, S represents the magnitude, r represents the epicentral distance and S and R are continuous random variables. The probabilty of occurrence of A, P[A], is given by the integration of the conditional probability of A given S and r times the independent probvbilities of s and r, $f_S(s)$ and $f_R(r)$, over all possible values of s and r. As is the case with any risk assessment model, (1) the spatial-temporal earthquake generation process and (2) the field of ground motion effects given an earthquake should be determined. In this study the following basic assumptions are adopted concerning these models.

A generalized form of the original Gutenbtrg and Richter (1958) relative frequency distribution of earthquake magnitudes expressed by a doubly-truncated linear recurrence relationship, with a lower bound, m_o, and an upper bound, m_1, is employed. The resulting distribution function is as follows:

$$F_M(m) = k_{m_1}\ [1 - e^{-\beta(m - m_o)} \qquad m_o \leqslant m \leqslant m_1 \qquad (2)$$

where β is the slope of the recurrence relationship and the factor

$$k_{m_1} = [1 - e^{\beta(m_1 - m_o)}]^{-1} \qquad (3)$$

is needed for normalization. Thus in the magnitude range of interest and in a given seismic source the earthquake occurences are random and specifically treated as Poisson events with a constant annual average arrival rate. The preference of the Poisson model is justified by its simplicity, its widespread use and because the results based on the Poisson model are generally in agreement with those based on other models especially in relatively higher magnitude ranges (Yücemen, 1978).

For numerical calculations the computer program prepared by Mc Guire (1976) is employed. The program has been found to be quite satisfactory for applications of such purposes.

RESULTS AND DISCUSSION

The maximum site intensities with return periods of 200 and 500 years are shown in Figs. 2 and 3 as iso-intensity contours based on the intensity attenuation relationship developed previously. Peak horizonal accelerations with the same return periods are provided in Figs. 4 and 5 as iso-acceleration contours (given in **Gals)** based on the acceleration attenuation relationship for hard soil (McGuire, 1978). These return periods correspond to annual probabilities of exceedance of respectively 0.005 and 0.002.

These maps will establish a more rational and consistent basis for a seismic hazard map because its contours represent equal probabilities of seismic exposure. Furthermore, the same rational basis can be easily kept in the future revisions of the map as new data becomes available.

Today's seismic resistant design procedures call for more than a single parameter, such as maximum intensity or peak acceleration, to describe the characteristics of the strong ground motion. For example the ATC-3 (Applied Technolog Council, 1978) code provides two hazard maps for the EPA (Effective Peak Acceleration) and the EPV (effective Peak Velocity) thereby to define the shape of the smoothed elastic design spectrum as the design tool. The return periods applicable for the earthquake resistant design of structures should be assessed with respect to the type and importance of the structures and the national socio-economic conditions. The return periods employed in the maps presented herein are generally valid for the dwellings and other routine commercial structures. For nuclear power plants, dams and other important engineering structures for which very long return periods are required these maps indicate a relative idea of the hazard. For maps depicting earthquake hazard for such long return periods a more extensive investigation and utilization of the geological data, historic earthquakes and relevant attenuation characteristics may be needed.

The earthquake hazard near the source boundaries are directly and strongly affected by the changes in these boundaries. The relationship between the neo-tectonic features and the macroseismic epicenters has guided us in the delineation of seismic source zones. Delineation of source zones by simple enclosure of the isolated groups of epicenters may provide wider source zones. However, such approaches lack the rational geo-tectonic basis and should not be pursued.

The following subjects are found to be worthy of more research owing to their likely impact on these hazard maps.

- Assessment of the recurrence rates on the basis of tectonic activity as evidenced by the morphology of faults.
- Procedures intended to increase the consistency and rationality of maximum magnitude assessments.
- Study of ancient earthquakes especially for hazard maps of long return periods.
- Incorporation of the anisotropic attenuation characteristics associated with long faults.
- Near-field parameters of strong ground motions.
- Rigorous assessment of the validity of various stochastic processes to model the earthquate occurrences.

It should be reiterated that this study represents a first attempt to the estimate the probabilistic earthquake hazard and it is intended to serve as a reference for more advanced approaches and to stimulate discussion and suggestions on the data base, assumptions and the inputs.

ACKNOWLEDGMENTS

This paper outlines and provides some preliminary results of an ongoing study regarding the probabilistic seismic hazard analysis of Turkey. The study is supported by the Turkish National committee an Earthquake Engineering and the Turkish Scientific and Technical Research Council. The assistance of Erdal Eren in determination of the source and attenuation characteristics and the valuable suggestions of Professors A. Gürpınar, S. Yücemen and L. Kavvas are gratefully acknowledged.

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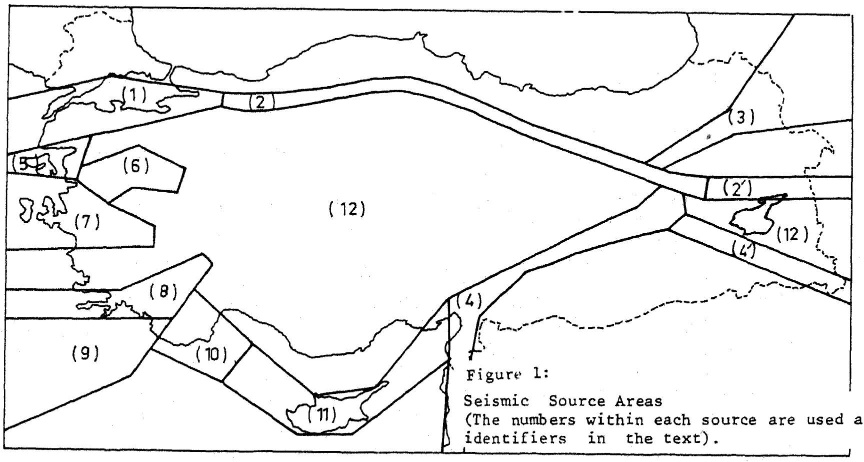

Figure 1:
Seismic Source Areas
(The numbers within each source are used as identifiers in the text).

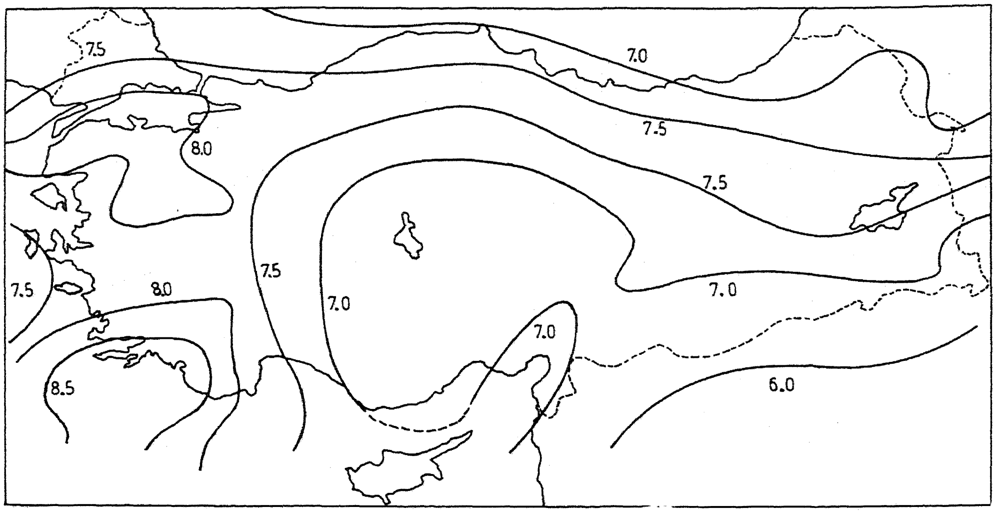

Figure 2: Preliminary Map of Intensity For 200 Years Return Period.
(Based on Local Intensity Attenuation Relationship).

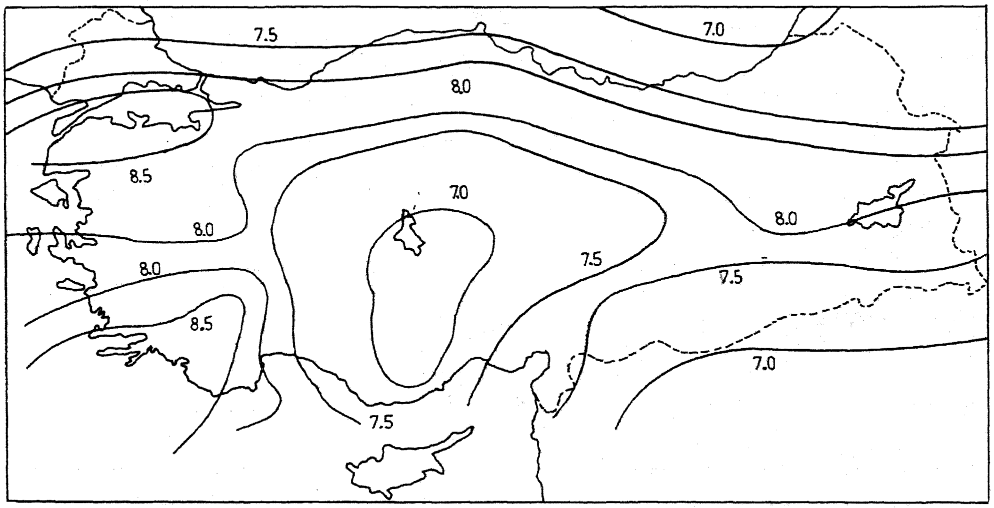

Figure 3: Preliminary Map of Intensity For 500 Years Return Period.
(Based on Local Intensity Attenuation Relationship).

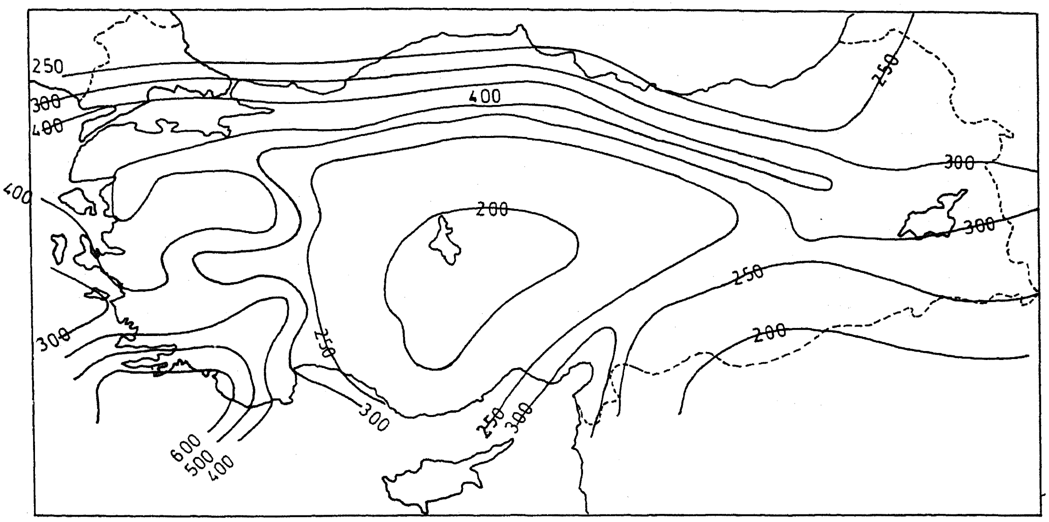

Figure 4: Preliminary Map of Horizontal Acceleration (Expressed in Gals) in Rock For 200 Years Return Period. (Based on McGuire (1978) Altenuation Relationship).

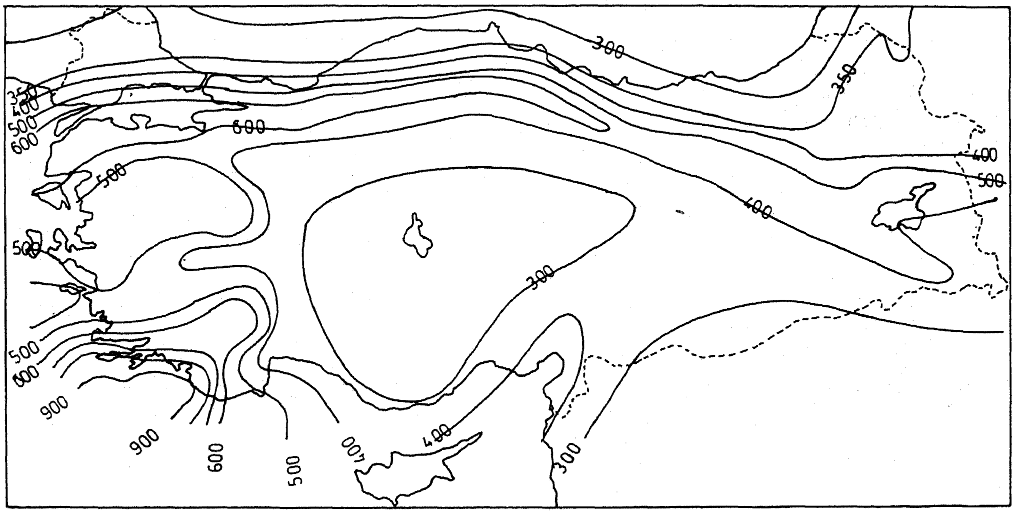

Figure 5: Preliminary Map of Horizontal Acceleration (Expressed in Gals) in Roch for 500 Years Return Period. (Based on Mc Guire (1978) Attenuation Relationship).