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# STUDY OF ISOSEOSMALS OF EARTHQUAKES

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## ABSTRACT

Isoseismal maps for 147 earthquakes in different parts of the ex-Yugoslav territory were analyzed for understanding of the relationship among intensity,magnitude and distance. Intensity versus distance data measured from the isoseismal maps,were fit to an empirical relation based on geometrical spreading and anelastic attenuation.

The whole investigation territory is divided into two atenuation regions, MS region with an energy absorption coefficient of 0.0495/km, and OS region with an absorption coefficient of 0.0023/km. The different rates of absorption can be explained as the result of slightly greater average focal depths in the OS than in the MS region, althouth the data are too scattered to prove that this is the cause.

Assuming a linear relationship between log(A/T) and Intensity value,the attenuation for the whole investigation territory is expressed by the equation, valid for $I(R) \geqslant IV(MCS)$:

$$I(R)=I_0+0.737-0.010R_e-1.234\log R_e$$

where $R_e$ is the epicentral distance given in kilometers

This realationship shows a fairly good agreement with isoseismals of many large events and may therefore be useful in providing realistic estimates of spatial attenuation and hence of design earthquakes for a given site. It can also be sometimes useful in estimating the epicentral intensity for an eartquake whose maximum intensity is not reliably known.

## KEYWORDS

Isoseismal maps; seismic energy density, absoption; regression analysis.

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## INTRODUCTION

In addition to providing material for statistical analysis, historical records provide valuable information concerning the macroseismic effects of earthquakes. These macroseismic data have been used in estimating the local intensity of the earthquakes and constructing isoseismal maps. Intensity refers to the degree of shaking experienced at a specified place during an earthquake, but it is not based on instrumental measurements.It is a rating assigned by an observer using a descriptive scale with grades from I to XII. After having assigned intensities in a felt area of an earthquake, contours are drawn separating regions of differing ratings. These contours known as isoseismals of the historical earthquakes tend to be influenced by population distributions. Additionally, isoseismal distributions are affected by geological factors, principally the surficial sedimentary terrain. However, isoseismal geometry in the epicentral regions of earthquakes is extremely important because it reflects the patterns of faulting associated with the earthquakes,no matter whether faults are visible on the surface or not.

## DATE BASES

The input data used in this study have been collected from the Atlas of Isoseismals Maps (Catalogue of Earthquakes) in the UNDP/UNESCO *Survey of the Seismicity of the Balkan Region(1974)* and from unpublished data on seismic intensities in the Balkan region up to 1994. It means that this paper follows a somewhat less sophisticated approach, but one which allows the inclusion of a considerably larger number of earthquakes. For each map accepted for further study, twenty four radii were drawn from the center of the region of maximum intensity,and the distance at which each radius intersects each isoseismal is measured, and later transferred to a computer card for regression analysis. The isoseimal map for one of the analyzed earthquakes is shown in Fig.1.The convention used in ambiguous situations is following:the cases where a single radius crosses the boundary of some particular intensity more than once, the crossing most distant from the origin was selected;when an isoseismal is drawn over water or drawn with a broken line to indicate uncertainty, it is not used. A computer program was written to examine the statistics of the distances to the isoseisms.

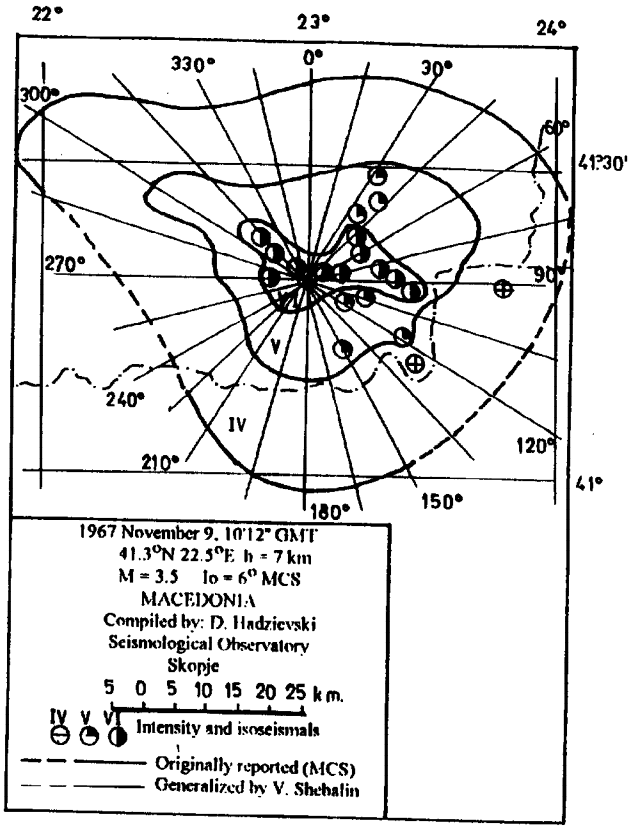

Fig. 1. Isoseismal map of the earthquake used in the analysis

After analysis of all maps, the following classification of data was made:

a)Data for whole investigation territory
c)Data with focal depth less and equal then 10km
d)Data with focal depth greater than 10km
e)Data on the MS region
g)Data on the OS region

The division into two regions (MS and OS) was performed on the basis of neotectonic zoning of the investigated area presented in Fig.2.

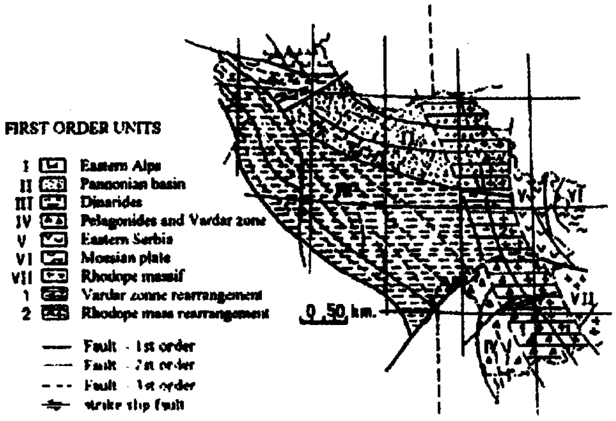

Fig. 2. Neotectonic zonation of former Yugoslav territory

## THEORY

Koveslgethy has shown that intensity as a quntity that describes a large number of points may express attenuation of the earthquake effect upon the surface, including a simple model of energy propagation, i.e., a point source that coresponds to the medium in which earthquakes take place.Koveslgethy's method is based on the Weber-Fechner's law referring to the state of some physical system when "intensity" is proportional to the log "input data". The main formula relating intensity and energy density to a large number of physical phenomena is of the following form:

$$I=a+b\log(E) \qquad (1)$$

The acceptance of the linear--log relationship between intensity and seismic energy density represents a rough schematic presentation of the very complex actual situation. This relationship is the basis of traditional empirical "macroseismic formulae" of the type invented by Kovesligetly,Blake, Shebalin and others and has been justified for processing of macroseismic data:

$$I=K_1+K_2\ln\Delta+K_3\,\Delta \qquad (2)$$

The basic concept of proportionality of earthquake intensity and log density of energy (relationship 1) at some location, or log amplitude of soil which is equivalent to the previous assumtion was accepted. It can be concluded that a large number of the mentioned authors propose empirical equation of the following type:

$$I(R)-I_0=a+bR+c\log R \qquad (3)$$

where I(R) is intensity at distance R from the epicenter of an earthquake with an epicentral intensity $I_0$ while "a","b","c" are coefficients corresponding to the investigated region. Relationship (3) provides results for some distance from the epicenter. For the analysis of seismic risk at smaller distances from the epicenter,it is assumed that attenuation doesn't exist. According to U.Chandra, this problem can be solved if R is replaced by R+D, where D is a constant for which holds the case that $I(R)=I_0$ for R=0, i.e.

$$I(R)-I_0=bR+c\log(1+R/D) \tag{4}$$

In this way,singularities for R =0 are eliminated whereby it is considered that the earthquake focus is at some depth below the surface.

## RESULTS

The functional relationships were obtained by using the regression analysis which include all radii for all $I_0$ and $I_1$, but has the tendency to emphasize the larger radii, i.e. ,all the radii are not treated equally with this method. Actually, such an analysis enables drawing of a line that provides the best analytical description of data.The following attenuation relations and corresponding standard errors $\sigma$ of ((I(R)-Io)were obtained. All earthquakes considered:

$$I(R)=I_o+0.737-0.010R-1.234\log(R+4.0) \qquad \sigma=0.388 \tag{5}$$

at focal depth less or equal to 10km:

$$I(R)=I_o+0.534-0.019R-1.095\log(R+3.0) \qquad \sigma=0.274 \tag{6}$$

at focal depth of over 10km:

$$I(R)=I_o+0.477-0.023R-0.533\log(R+8.0) \qquad \sigma=0.370 \tag{7}$$

for the region MS:

$$I(R)=I_o+0.428-0.019R-0.881\log(R+3.0) \qquad \sigma=0.373 \tag{8}$$

for the OS region:

$$I(R)=I_o+0.752-0.008R-1.243\log(R+4.0) \qquad \sigma=0.407 \tag{9}$$

Presented in Table 1 are the values of coefficients a,b and c with their standard deviations and corresponding coefficients of inelastic attenuation ($\gamma$). As a by-product of the analysis this procedure yielded improved estimates of $I_0$ (presented in Table 2 and the coefficients a,b and c,in Table 3) for each investigation group of data. The epicentral intensities thus derived are based on analysis of all isoseismal contours and are therefore independent of the subjective judgment of assigning intensity at any observation point. At the end here is given a relationship between intensity and all other macroseismic parameters epicentral intensity,magnitude epicentral distance and focal depth for the whole data set as well as the MS and OS region (Table 4).

Table 1. Values of the a,b and c coefficients of the $I=f(I_0,R)$relationship with their standard devitaion and coefficient of absorption,$\gamma$

| Region | a±σ | b±σ | c±σ | γ |
|---|---|---|---|---|
| Y | 0.737+0.064 | -0.010+0.006 | -1.234+0.046 | 0.0188 |
| Y,h<10km | 0.535+0.086 | -0.019+0.001 | -1.095+0.066 | 0.0390 |
| Y,h>10km | 0.477+0.047 | -0.023+0.001 | -0.533+0.095 | 0.0993 |
| MS | 0.428+0.077 | -0.019+0.001 | -0.881+0.057 | 0.0495 |
| OS | 0.752+0.093 | -0.008+0.001 | -1.243+0.065 | 0.0023 |

Table 2. Dependence of epicentral intensity $I_o$ on magnitude and focal depth

| Region | Relatinship $I_0 = f(M,h)$ | σ |
|---|---|---|
| Y | $I_o(M,h)=2.480+1.335\ M-2.194\log h$ | 0.461 |
| MS | $I_o(Mh)=2.044+1.498\ M-2.478\log h$ | 0.451 |
| OS | $I_o(M,h)=2.630+1.267M-2.066\log h$ | 0.467 |

Table 3. Values of a,b and c coefficients of the $I_o=f(M,h)$

| Region | a±σ | b±σ | c±σ |
|---|---|---|---|
| Y | 2.480+0.395 | 1.335+0.073 | -2.194+0.175 |
| MS | 2.044+0.541 | 1.415+0.096 | -2.478+0.303 |
| OS | 2.630+0.557 | 1.266+0.103 | -2.066+0.217 |

Table 4. Dependence of intensity on magnitude,focal depth and epicentral distance

| Region | Relationhip $I = f(M,h,R_e)$ |
|---|---|
| Y | $I(M,h,R)=3.217+1.335M-2.194\log h -0.010R-1.234\log (R+13)$ |
| MS | $I(M,h,R)=2.472+1.498M-2.478\log h-0.019R-0.881\log (R+11)$ |
| OS | $I(M,h,R)=3.383+1.267M-2.066\log h-0.008R-1.243\log (R+15)$ |

The results of all these computations are presented in the form of Intensity-logR distributions, as shown in Fig.3 for five selected data sets. Presented in Fig.4 is the intensity attenuation with epicentral distance for the territory of U.S.A. given by many authors and the intensity attenuation obtained on the basis of these investigations. It is evident that the physical characteristics of rock masses that are present from the seismic energy source to the surface are such that the intensity attenuation is higher for the territoty which is the subject of this investigation, than that for the territory of U.S.A., i.e., the velocity of seismic energy propagation from the source to the surface is lower for the ex-Yugoslav territory than that for USA.

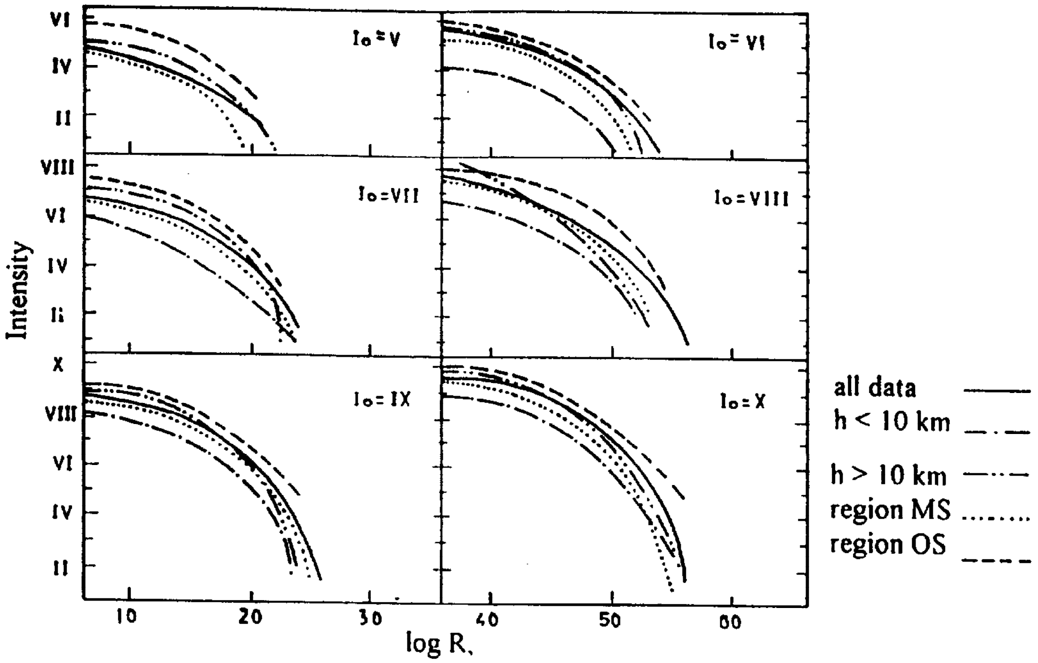

Fig. 3. Intensity - log (distance) plot for all the investigation data sets

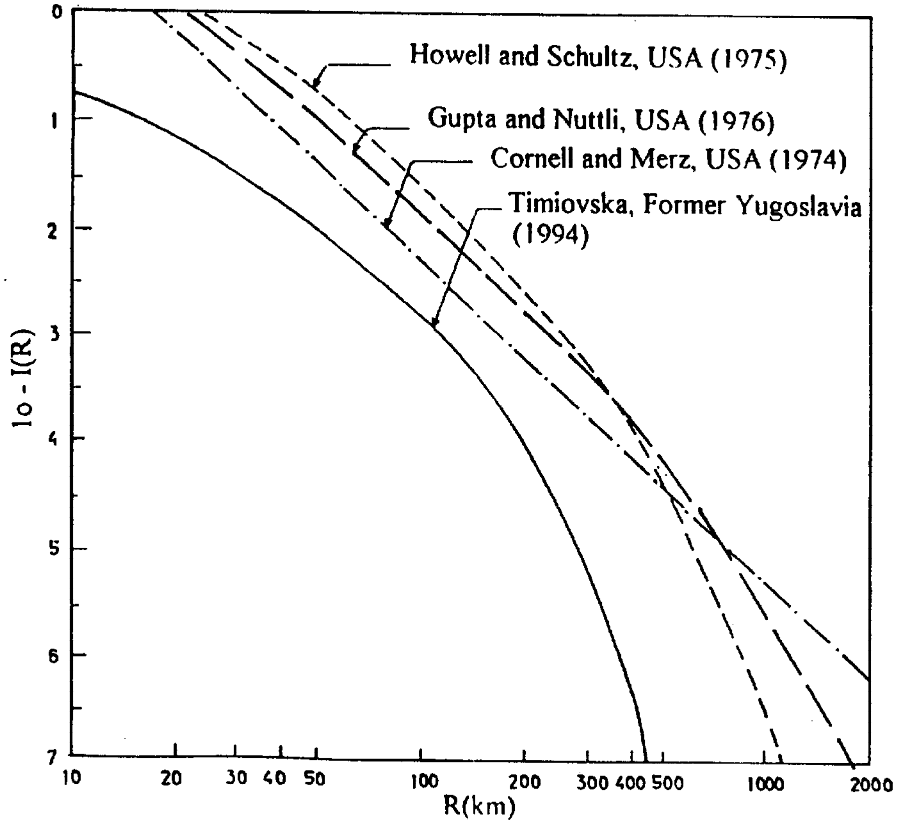

Fig. 4. Plots of Io - I(R) versus R for USA done by several authors and plots obtained for former Yugoslavia

## CONCLUSION

Although, the above given relationships yelds initial estimates of possible intensity level, irrespective of the focal depth and neotectonic zonation of an area, nevertheless the knowledge of such estimates is essential the first stages of determining the seismic hazard of a particular site.

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