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FRACTAL PROPERTIES OF THE MEDITERRANEAN SEISMOTECTONIC MODEL FOR SEISMIC HAZARD ASSESSMENT

B. Ranguelov
BAS
Acad. G. Bonchev str. Bl. 3
Sofia 1113, Bulgaria

S. Dimitrova
BAS
Acad. G. Bonchev str. Bl. 3
Sofia 1113, Bulgaria

D. Gospodinov
BAS
Acad. G. Bonchev str. Bl. 3
Sofia 1113, Bulgaria

G. Lamykina
PIG – FEB, RAS
Radio str. 7
Vladivostok 690068, Russia

ABSTRACT
The seismic hazard assessment of the big regions (such as Mediterranean) needs a regional seismotectonic model, which reflects the main seismogenic properties of the different seismogenic zones. Several models have been created during the last several years. A common work combining all available information about the hazard's model covered the whole Europe and Mediterranean region produced the general map - Jimenez, M. et al., (2001). This map is the target of thas study. We studied the compiled map of the model. The seismic zones fragmentation in space is investigated. The fractal dimensions and the fractal coefficients are established. This work is important for the seismic hazard assessment and its properties in the different regions.

INTRODUCTION

The present study focuses on the estimation of the fractal properties and coefficients of the seismogenic zones in the Mediterranean region. The area is divided into several seismotectonic provinces in accordance with the corresponding fragmentation and the specific seismogenic properties of the earth crust for the separate zones. The Mediterranean seismotectonic model (MSM) is presented in M.Jimenez et al. (2001). The separate zones could be characterized by their specific seismogenic properties, which could lead to different seismic impact on buildings and constructions. In that way this analysis gives the possibility for zone identification and comparison between different provinces each of them being most probably characterized by specific seismic hazard.

The classical example of a fractal object is defined by Mandelbrot (1982). If the length of an object P is related to the measuring unit length by the formula

$$P \sim l^{1-D} \qquad (1)$$

then P is a fractal and D is defined as the fractal dimension. Beno Mandelbrot gave this definition in the early 60-s of the 20-th century. His ideas support the view, that simple geometric forms can not describe many objects in nature. He considered that they have different levels of geometric fragmentation. It is expressed in irregularities of different scale – from very small to the quite big ones. This makes the measuring unit is extremely important, because measuring of the length, the surface or the volume of the irregular geometric bodies is strongly dependent on the smallest measuring unit in a way that the parameter value changes may vary hundred to thousand orders. This fact was first determined when measuring the coastal line length of West England and the results gave Mandelbrot (1982) the idea to define the concept of a fractal.

In geology and geophysics it is accepted that definition of the different 'fractals' as real physical objects is most often connected to fragmentation. This reveals that each measurable object has a length, surface or volume, which depends on the measuring unit and the object form irregularity. The smaller the measuring unit is, the bigger the common sum for the linear dimension of the object is and vice versa. The same is valid for 2D and 3D objects.

Another definition of a fractal can be made by the relation between the serial number of measuring to each of the measuring units and the object dimensions. If the number of the concrete measurement with a chosen linear unit is bigger than r, then it may be presented by:

$$N \sim r^{-D} \qquad (2)$$

and the fractal is completely determined by D as its characteristic fractal dimension. Applying this definition for the elements of faulting and faults fragmentation, some authors use this idea to depict formal models of the earth crust fragmentation established by Turcotte (1986), which indicate the level of fracturing of the upper earth layers.

From a physical point of view these models are acceptable in most cases considered for example by Ranguelov and Dimitrova (2002).

METHODOLOGY

Turcotte (1986) developed the theoretical approach for the linear case and for the 2D and 3D cases. He focuses his attention on the relations between the smallest measuring unit and object's size in analyzing linear, 2D and 3D objects (fig. 1).

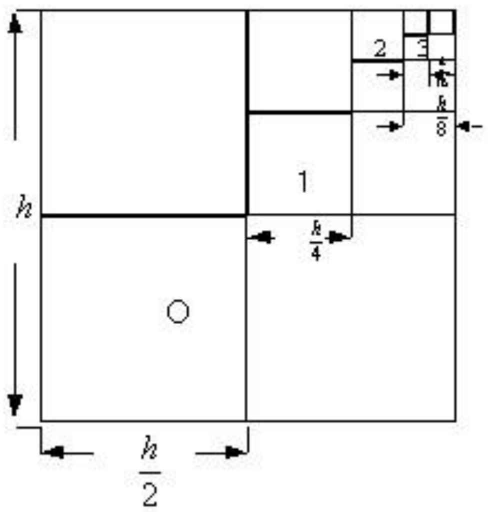


Figure 1. Simple fragmentation measuring of a quadrate with side length h (0), h/2 (1), etc.

If l is the measuring unit and with m we denote the obtained value for N at each measuring cycle, then the common sum of the lengths N at level m according to Turcotte is (1986)

$$N_m = (1-p_c)(1+\frac{n}{m}p_c+[\frac{n}{m}p_c]^2 \ldots [\frac{n}{m}p_c]^m) \quad (3)$$

where Pc denotes the probability for measuring each length for the corresponding cycle of measurements.

Using formulae 1 and 2 by Turcotte we obtain the formula

$$\frac{N_{m+1}}{N_m} = 2^D \quad (4)$$

which is valuable for the linear elements and

$$\frac{N_{m+1}}{N_m} = \left(2^2\right)^D \quad (5)$$

which is valuable for the surface case.

Applying formulae 2 and 3 for the mapped earth crust destruction lines in Bulgaria by T. Tzankov et al. (1998), led to obtaining reasonable results by using the above model. This motivated us to verify this approach in analyzing the elements of the Mediterranean seismotectonic model. The existence of different geometrical objects of similar type like the different seismic hazard zones in various Mediterranean areas, makes it suitable to use such an approach when determining the fractal features of the considered seismotectonic model.

MEDITERRANEAN SEISMOTECTONIC MODEL (MSM) AND ITS FRACTAL PROPERTIES

To study the fractal features of the Mediterranean seismotectonic model offered by M.Jimenez et al. (2001), we have used data from the map (Seismicity Source Regions for the Mediterranean Region). The map scale is 1:28 000 000.

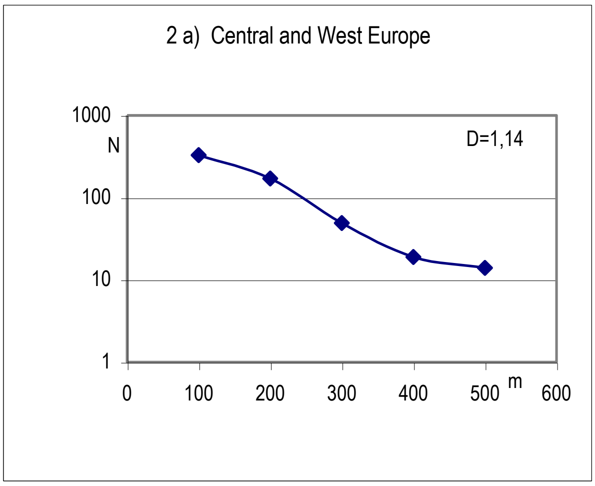
We have determined the number and the size of all lines delineating each of the surface elements of the model. The error in determining the size is less than 5%. The authors of the map have divided the region into several seismotectonic provinces (we follow their denoting):

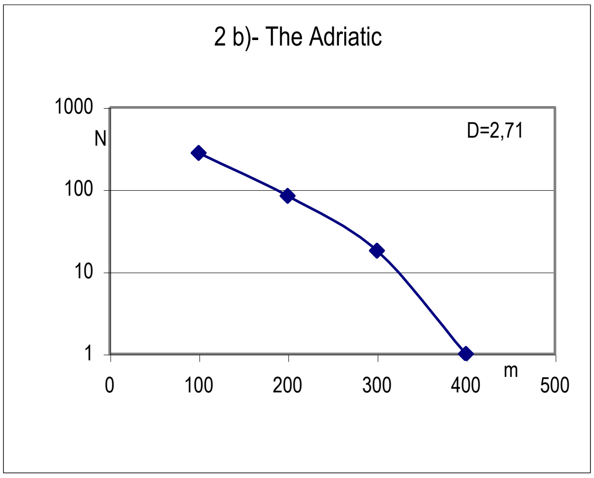
- The Adriatic (AD)
- Central and West Europe (CWE)
- The Pyrenees and West Africa (PWA)
- Greece (GR)
- Bulgaria and the Northern Balkans (BG NB)

Each province was considered separately at first. Finally some general studies have been made for the whole Mediterranean region.

The lengths of the delineating lines for each seismotectonic zone vary between 100-500 km (they are very rarely bigger but the number of such cases is small enough). Cumulative plots have been developed in order to calculate the fractal dimension of each zone.

The results are presented on fig.2(a-f)





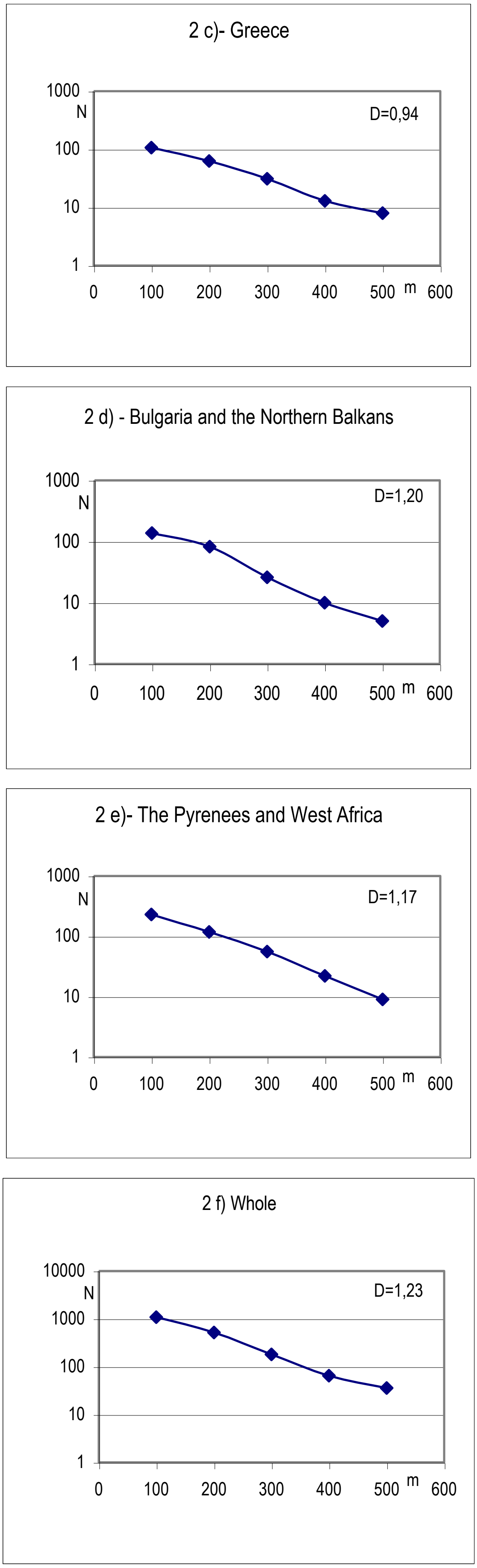


Figure 2 (a-f). Cumulative graphs for the MSM with the established fractal dimensions (linear elements) for the different zones (a-e) and in general (f).

We have also determined the surface fractal dimensions of the separate seismotectonic elements for the same region.
All surface areas have been determined and we have plotted the relations - number – area for each zone. For this purpose we have used the map M.Jimenez et al. (2001) , which is in a scale 1:30 000 000. The measured surface areas vary from 500 to 2500 km^2.

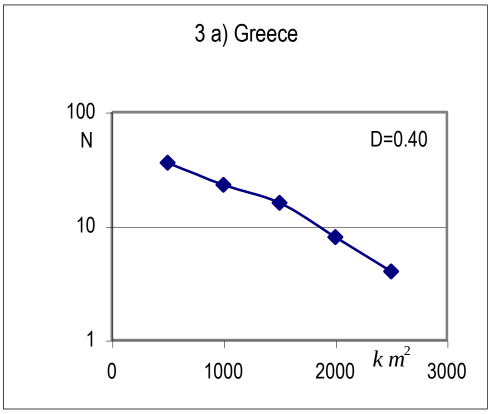
ANALYSIS AND SYNTHESIS

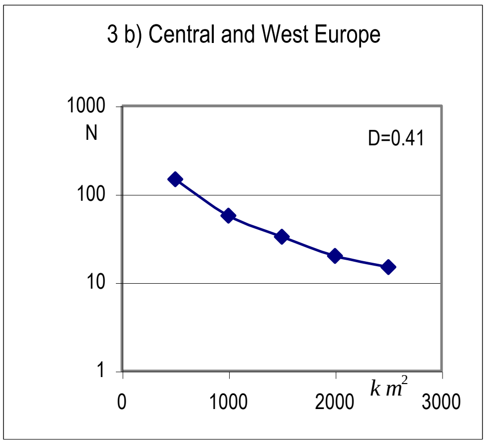
The obtained results for the different provinces reveal (table 1) :

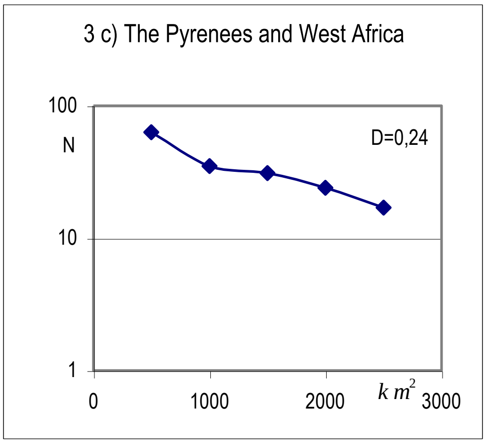
Table 1. Fractal dimensions for the linear (l) and surface (S) elements of the MSM

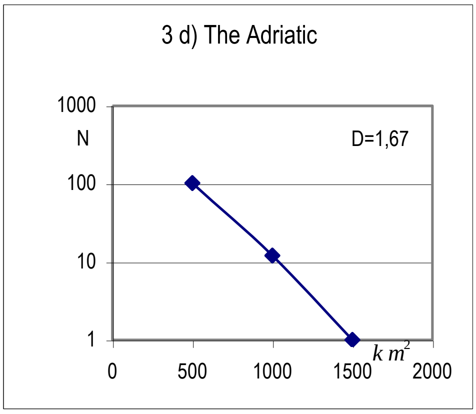
zone	$D_{(L)}$	$D_{(S)}$
AD	2,71	1.67
CWE	1,12	0.41
PWA	1,18	0.24
GR	0.94	0.40
BG NB	1.20	0.25
общо	1.23	0.38

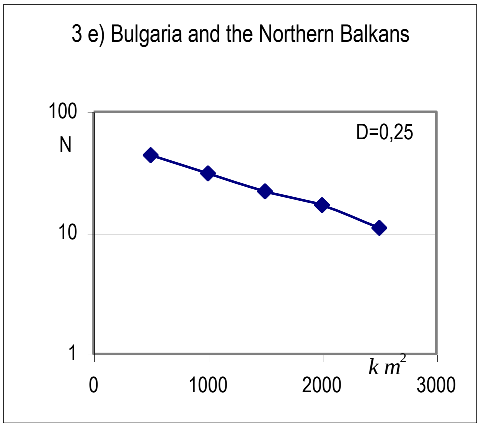
- The dimension values for the ‘Adriatic’ zone differ substantially from the other zones values. This concerns both the linear elements and the 2D elements, and it is reflected in both studied parameters at the level of non-linearity (the D-value respectively) being the biggest.
- All remaining zones are similar according to their non-linear behavior (considering the linear boundaries). The dimension values vary from 1.1 to 1.25 with Greece making an exception with a dimension under 1.0 (0.94)
- Regarding the 2D fractal features, the differences are smaller with the exception of the Adriatic zone again. Some grouping can be identified of different zones according to their fractal dimension values – ‘Greece’ and ‘Central and West Europe’ (0.41-0.40). These zones are quite different by their seismic activity and seismicity patterns, but they are similar concerning their seismically hazardous areas from “fractal” point of view.
- Other similar zones (by their linear fractal dimensions) are ‘The Pyrenees and West Africa’ and ‘Bulgaria and the Northern Balkans’ (025-0.24). These provinces have not similar geodynamic features but they are formally similar for sure according to the distribution of their seismically dangerous areas. In one way or another, the hazardous areas have similar sizes.











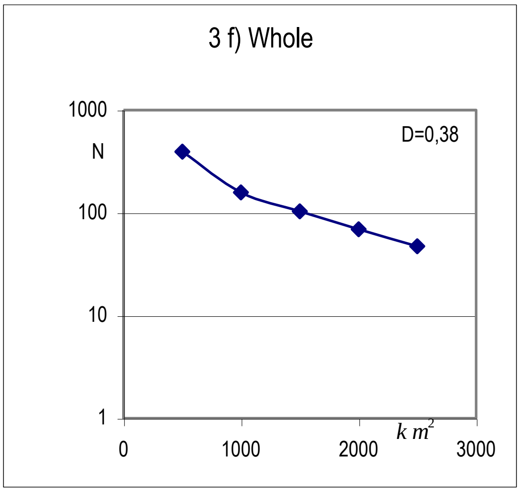


Figure 3 (a-f). Cumulative graphs for the MSM with the established fractal dimensions (surface elements) for the different zones (a-e) and in general (f).

CONCLUSIONS

The obtained results reveal that the applied approach can be useful in comparing the behavior of the seismogenic elements of the different seismotectonic provinces. The existence of clearly defined non-linear features of the seismic hazard areas' distribution shows similarity or non-similarity. Simple elementary relations can not describe this important sensitive part of human knowledge about the practical assessment of the seismic hazard. It becomes evident that more punctual and refined methods of the mathematical analysis are obligatory in order to avoid generalizations made only on analogs, which was done in many cases up to now.

The obtained results can serve as a base for developing of 'local' requirements and codes, regarding seismic safety in construction and on the general. The similar seismic hazard features in the different countries can be used for applying and/or adapting of already developed and used in practice regulation documents.

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