ON STRESS STATE EVOLUTION IN THE Vrancea (Romania) Seismic Region

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About a decade ago, we estimated (D. Enescu and B. D. Enescu [4]) that the next strong earthquake in Vrancea region was not going to happen until the end of 2005. The time has come for us to be more specific and say when after 2005 it can be expected to occur. Our researches originally [4] led to two hypotheses. In this paper we form by means of Benioff graphs a first hypothesis with respect to the maximum possible magnitude that Vrancea earthquakes can attain during the periods 2006–2010 and 2011–2015.

Key words: stress state, time series, Benioff graph.

1. INTRODUCTION

The subject has been approached in different ways in several studies. First Iosif and Radu [1] analyzed stress state evolution in Vrancea using Benioff graphs [2]. Their paper, however, was confined to past events (previous to 1958) and stopped short of applying the Benioff graphs to identify any characteristics of how the stress state in Vrancea seismic focus might evolve from then on.

In 1975, Enescu and Ianas [3] tackled the subject. They used predictive Wiener filter to extrapolate into the future the time series represented by the time distributions of the square roots of the seismic energy emitted by Vrancea foci in the periods 1861–1970 and 1801–1970.

Their extrapolation was confirmed for the time interval 1981–1990 by the earthquake of August 30, 1986 (\(M_{GR} = 6.9\)–7.0) and those of May 30 and 31, 1990 (\(M_{GR} = 6.7\) and 6.1, respectively). There was no confirmation for the time interval from 1976 to 1980, because observation data for the time periods they had originally considered were incomplete. In fact, all results in both [1] and [3] were especially distorted by the lack of complete observation data for the periods the authors had considered, i.e., up to 1958 and respectively, up to 1970. One thing was clear, though, namely that the predictive Wiener filter seemed apt to yield satisfactory predictions of Vrancea earthquakes provided that longer
periods – as long as, say, through 2005 – than the one analyzed in [3] were taken into consideration.

In a paper [4] published in 1996, we demonstrated as a near certainty that the next strong Vrancea earthquake \( (M_{GR} \geq 6.5(6.7)) \) could not possibly happen any earlier than the end of 2005. This prediction has virtually been verified already. As to when exactly after 2005 it would occur, we only made some assumptions [4].

In one of them, we assumed that the next Vrancea seism of Gutenberg-Richter magnitude \( M_{GR} \geq 6.5(6.7) \) would happen in any of the years 2006, 2007, or 2008 [4]. According to a different hypothesis we made in [4], we inferred the next Vrancea seism of \( M_{GR} \geq 6.5(6.7) \) would occur later on, perhaps even later than 2010.

Some would-be soothsayers relying on their half-digested version of these hypotheses made fools of themselves on various TV shows and in newspaper interviews while all they could come up with was a terribly unimaginative approach to the issue.

In an article [6] appearing in 2005 and based on data provided by professionals, two of these professionals (see [6], p. 24) even claimed credit for one of the main conclusions of our papers [4; 5], which were published ten years and twenty-three years, respectively, prior to article [6].

In the circumstances, we found it appropriate to approach the subject once again in this work. We first applied Benioff graphs plotted for the Vrancea region to study the way in which the state of stress evolved there in the past. Taking this evolution as a law, we extrapolated to the near term to find what might be the parameters of the next strong earthquake in Vrancea.

2. THEORETICAL PART

It is considered that part of the elastic energy \( E \), which is stored up during the earthquake preparation stage, changes into seismic energy \( E_s \). What matters, as we plot the Benioff graph, is that the ratio

\[
e = \frac{E_s}{E}
\]

is always the same for a given seismic zone.

The ratio \( e \), known as seismic efficiency depends on, among other things, the characteristics of that particular seismic zone. The seismic energy \( E_s \) is obtained, according to Benioff [2], from the relation

\[
E_s = C^2 F_m^2
\]
where $C$ is a coefficient that depends on the extent of the deformed area, elasticity module, and seismic efficiency; $F_m$ is the average elastic force preceding an earthquake. So, the square root of the energy $E_s$ is proportional to the elastic force that generates the earthquake, i.e.

$$E_s^{1/2} = CF_m.$$  

### 3. THE BENIOFF GRAPHS AND THEIR INTERPRETATION

Plotting a Benioff graph actually adds up to determining the energy that a seismic focus will release in the form of elastic waves over a period of time the length of which is chosen according to one’s purpose. Using the values of the magnitude $M$, the seismic energy $E_s$ can be determined by the relation:

$$\log E_s = a + bM$$  

As demonstrated in our earlier paper [7], if the Gutenberg-Richter magnitude $M_{GR}$ is used, the valid coefficients for the intermediate depth Vrancea earthquakes are:

$$a = 11.8 \text{ and } b = 1.5 \text{ (Gutenberg and Richter, [8])}$$  

If the moment magnitude $M_W$ is used, we have:

$$a = 10.48 \text{ and } b = 1.63$$  

The magnitude $M$ data (values; relations between $M_W$, $M_{GR} = M_S$, $M_D$ or $M_L$ and maxim macroseismic intensity $I_{max}$) were taken from the Catalogues of Romanian earthquakes, compiled by National Seismological Department over the years [9; 10].

By calculating with equation (4) the seismic energy $E_s$ for Vrancea earthquakes since 1780 to date, we were able to plot the Benioff graph in Fig. 1. We picked the year 1780 because earthquake catalogue data were much too sparse prior to that date. The time was represented in decades on the abscissa, while the ordinate shows the sums of the square roots of energy $E_s$ every five years; in other words, a five-year sampling step was used for the time series. As seen in Fig. 1, the quantity $\sum E_s^{1/2}$ is represented “by cumulation”. The graph therefore looks like a stairway with unequal steps (Fig. 1).

Also appearing on the time axis (Fig. 1) are the 36-to-38-year cycles we first singled out as early as 1983 [5] and then corrected and reused in [4] for Vrancea earthquake prediction. It should be remembered that a half cycle is characterized by earthquakes of magnitudes $M_{GR} \leq 6.5(6.7)$, while earthquakes
of $M_{GR} \geq 6.5(6.7)$ are typical of the other half (Fig. 1). Such half cycles are obviously 18 or 19 years long; in one case alone we have a 20-year half cycle [4].

The straight lines traced on the stepwise graph (Fig. 1) express the average slope $\frac{\Delta \left( \sum E_i^{1/2} \right)}{\Delta t}$ of every Benioff graph segment corresponding to a half cycle. As expected, the slope $\frac{\Delta \left( \sum E_i^{1/2} \right)}{\Delta t}$ (Fig. 1) for every half cycle with $M_{GR} < 6.5(6.7)$ is less steep than that for its counterpart characterized by $M_{GR} \geq 6.5(6.7)$.

The above description of the graph in Fig. 1 in fact describes the cyclic nature of Vrancea earthquakes and can be used to predict them, as has been done already in our papers [4] and [5].

Analyzing the graph, we notice once again that data are incomplete and magnitudes are underrated for the period up to 1935, which is when a seismic network began to be established in Romania. In trying to predict the next strong Vrancea earthquake, we therefore used two variants of the Benioff graph (Fig. 2) for the period after 1935. One variant (Fig. 2) used like the graph in Fig. 1 the average slopes $\frac{\Delta \left( \sum E_i^{1/2} \right)}{\Delta t}$ of the half cycles.

In Fig. 2 we found the straight lines $\alpha$ and $\gamma$ to be parallel to each other. For extrapolation, we admitted that the straight lines $\beta$ and $\delta$ (Fig. 2) were also parallel, namely that:

$$\gamma \parallel \alpha; \quad \delta \parallel \beta$$

Likewise, we admitted the straight lines $Z$ and $\delta^x$ (Fig. 2) were also parallel, namely that:

$$\delta^x \parallel Z$$

The occurrence probability of the next Vrancea earthquake of magnitude $M_{GR} \geq 6.5(6.7)$, in the 2006–2008 time window, is $P \geq 67\%$ (see Enescu, 1996 [4]).

In this variant, it is probable ($P \rightarrow 100\%$) that the upper limit of the time window be bigger than 2008 (for example, 2011 (see Enescu, 1996 [4]).

By extrapolating from data in Fig. 2, we were to form a first hypothesis with respect to the highest possible magnitude $M_{max}$ that Vrancea earthquakes can attain during these two time intervals are 2006–2010 ($M_{GR}^{max} \cong 6.3(6.4)$ (?)) and 2011–2015 ($M_{GR}^{max} \cong 7.0(7.2)$ (?))
REFERENCES

Fig. 1. – Benioff graph for Vrancea earthquakes occurred in the period 1780–2005, with average slope for every half cycle.
Fig. 2. – Same as Fig. 1 for the period 1936–2005.