SEISMIC ASSESSMENT OF A SITE USING THE TIME SERIES METHOD

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Abstract

1. To increase the safety of a **NPP** located on a seismic site, the seismic acceleration level to which the **NPP** should be qualified must be as representative as possible for that site, with a conservative degree of safety but not too exaggerated.

2. The consideration of the seismic events affecting the site as independent events and the use of statistic methods to define some safety levels with very low annual occurrence probabilities (**10^{-4}**) may lead to some exaggerations of the seismic safety level.

3. The use of some very high values for the seismic accelerations imposed by the seismic safety levels required by the hazard analysis, may lead to very expensive technical solutions that can make the plant operation more difficult and increase the maintenance costs.

4. The consideration of seismic events as a **time series** with dependence among the events produced, may lead to a more representative assessment of a **NPP** site seismic activity and consequently to a prognosis on the seismic level values to which the **NPP** would be ensured throughout its life-span. That prognosis should consider the actual seismic activity (including small earthquakes in real time) of the focuses that affect the plant site.

The method is useful for two purposes:

a) research, i.e. homogenizing the history data basis by the generation of earthquakes during periods lacking information and correlation of the information with the existing information. The aim is to perform the hazard analysis using a homogeneous data set in order to determine the seismic design data for a site;

b) operation, i.e. the performance of a prognosis on the seismic activity on a certain site and consideration of preventive measures to minimize the possible effects of an earthquake.

5. The paper proposes the application of **Autoregressive Time Series** to issue a prognosis on the seismic activity of a focus and presents the analysis on **Vrancea** focus that affects **Cernavoda NPP** site, by this method.

6. The paper also presents the manner to analyze the focus activity as per the new approach and it assesses the maximum seismic acceleration that may affect **Cernavoda NPP** throughout its life-span (~ **30 years**).

7. Development and application of new mathematical analysis method, both for long - and short - time intervals, may lead to important contributions in the process of prognosis the seismic events in the future.

1. INTRODUCTION

Earthquakes are very violent phenomena which affect people life as well as the building safety. By now, deterministic correlation regarding the moment of their occurrence and their violence has not been assessed and that is the reason why its analysis was made by statistic methods.

The statistic approach is imposed by the fact that the seismic history of a focus has presented a relatively small number of accurate determined events. Historical information are not continuous and the moment of an earthquake occurrence and especially its violence, evidence a high degree of uncertainty. For that reasons, by now, the seismic activity of a focus has been approximated by **Poisson** type models in which events, considered independent, are the annual maximum magnitudes or for certain time-interval.

If more possible alternatives for the parameters of a focus are considered, e.q. the maximum possible magnitude, focus depth, epicentrum distance, etc. and certain levels of confidence are associated to them, one can determine the effect of that focus on a site, by the determination of hazard curves. Based on these earthquakes it is possible to determine the maximum acceleration on site, considering all the possible alternatives and their percentage of confidence.

Consideration of earthquake generation in a certain focus as completely independent elements may be quite a wrong approximation which, usually leads to overestimation.

The approach of a focus activity by means of time-series in which the events are supposed to be dependent on one another and their occurrence is generated by deterministic causes, to which aleatory causes are overlapping, is more realistic, we think.

The main problem today is whether the existing data are sufficient to assess the deterministic component and make possible a correct assessment of the model parameters both for deterministic conponent and for statistic ones.

This paper is an analysis of **Vrancea** seismic focus (the main focus which affects **Cernavoda NPP** site) applying the method of Auto-Regressive (**AR**) time-series.

The paper is aimed to evidence the possibilities of analyzing a focus by means of **AR** models. It presents several different approaches and points out the existence of an overlapping of periodical events components ranging between **2** years and **46** years, events which might be correlated to some geological phenomena regarding the earth thermodynamics and the plate tectonics or to some phenomena related to the mechanics of planets like earth tide.

Due to a lack of representative series of the input data, the paper presents only few different hypothesis which, to a certain extent, may alter the results and for that reason the analysis is considered preliminary and it should be remade by reviewing the representative package of input data.

2. SEISMIC HAZARD CURVES AT CERNAVODA NPP

Cernavoda NPP site seismicity is determined by **Vrancea** intermediate focus whose depth ranges between **90 - 150Km**, and is located at **190 Km** epicentrum distance to the **Cernavoda NPP** site evidencing a maximum credible magnitude of **7.5**, according to some authors, and **7.8** as per others.

Cernavoda NPP site is also affected by **Sabla-Dulovo**, **Galati-Tulcea** seismic area and the smaller amplitude local **Vrancea** earthquakes (see **Figure 2.1**).

To determine the seismic hazard curves on the site, **Poisson** type process which represents the probability of occurrence of at least one earthquake having the magnitude higher than **M** value, was considered [**Ref. 1, 7**].

That probability is given by the relation:

$$p(M,t) = 1 - e^{-\nu(M)t} \quad (2.1)$$

where, ν(**M**) is the average annual number of earthquakes having the magnitude grater then **M**, given by the magnitude - frequency recurrence law. For **Vrancea** intermediate focus, the non-corrected magnitude - frequency recurrence law for the maximum credible magnitude is:

$$LgN(m \geq M) = 716.3 - 626.4M + 218.4\,M^2 - 38.0\,M^3 + 3.3\,M^4 - 0.1\,M^5 \quad (2.2)$$

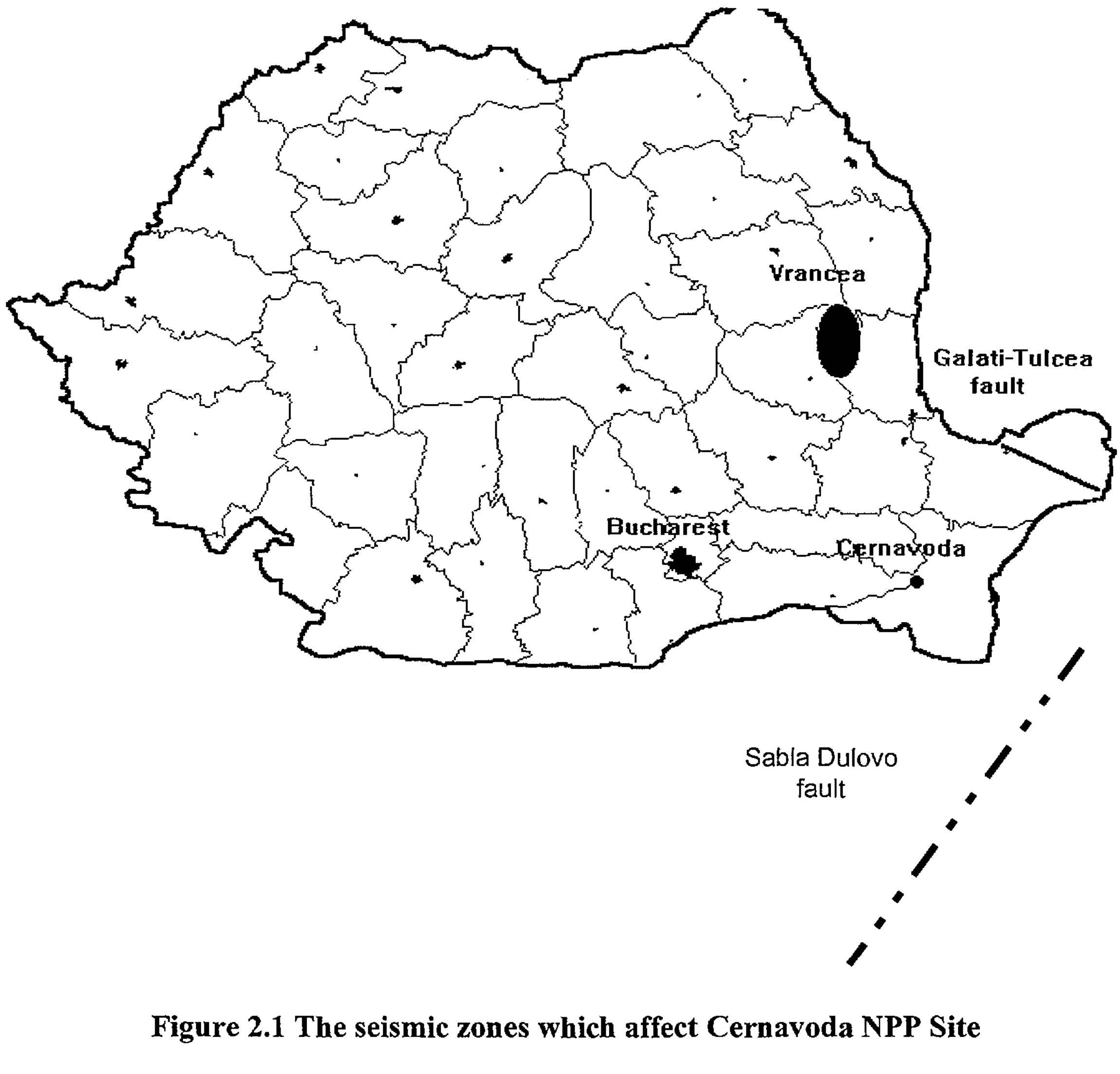

Figure 2.1 The seismic zones which affect Cernavoda NPP Site

The law of seismic acceleration attenuation with epicentrum distance was determined by processing the recordings made since **1977** till now and it is given by equation (2.3) for **Vrancea** intermediate focus [**Ref. 2**]:

$$Acc = e^{4.16765+1.11724M}(R_h+40)^{-1.44067}; \qquad \sigma_{\ln(Acc)} = 0.47607 \qquad (2.3)$$

In case of **Sabla-Dulovo** and **Galati - Tulcea** fault, similar analyses have been done and their intermediate results are not presented herewith [**Ref. 2**].

The **Figures 2.2-2.3** present the magnitude frequency law as well as the seismic hazard curves for **Cernavoda NPP** site for medium value of **120 Km** hypocentrum depth and epicentrum distance **190 Km** using the data base of **Ref. 6**.

Analyzing the results obtained we can say that:

1. the seismic zone which determines the seismic risk for **Cernavoda NPP** is ***Vrancea*** zone. The predominant influence of intermediate **Vrancea** earthquakes in the assessment of the seismic hazard on **Cernavoda NPP** site is due to *the high frequency of earthquakes occurrence and to the high maximum magnitudes as to the other seismic zone.*

2. The value of peak ground acceleration for an annual exceeding probability of 10^{-3}, corresponding to the **DBE** design acceleration for **Cernavoda NPP** site, is **0.175 g** from *the median curve attenuation + one standard deviation* that is lower than **0.2 g** as considered in the seismic qualification of **Cernavoda NPP** Unit 1.

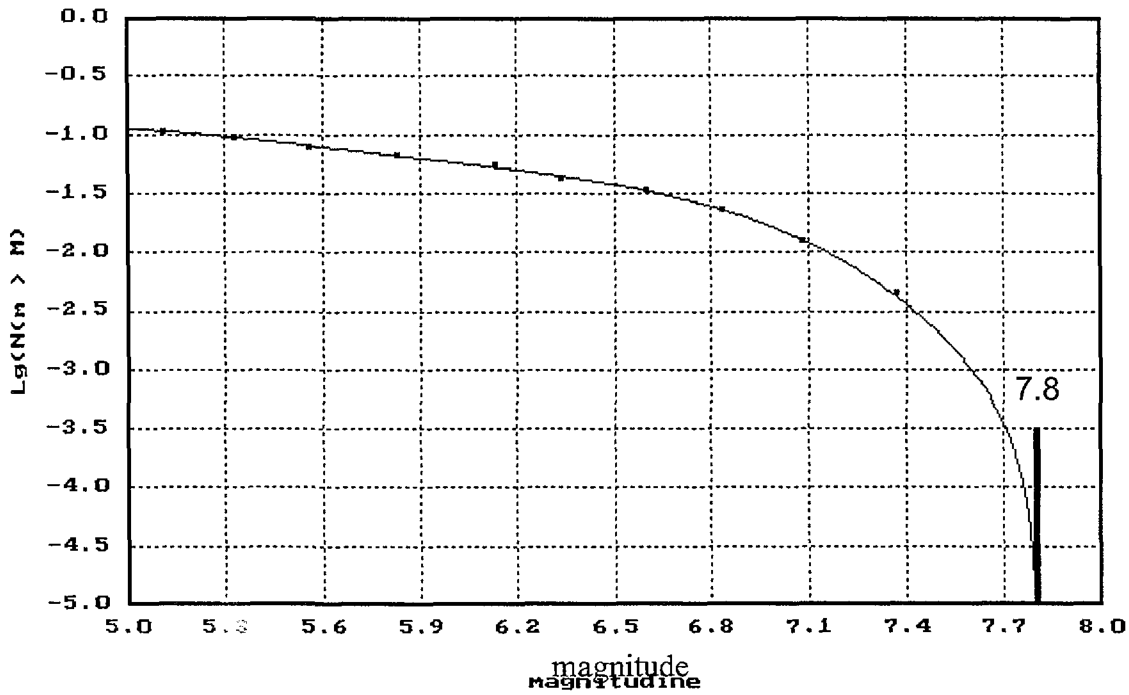

Figure 2.2 Law of the Cumulative Frequency-Magnitude for the 7.8 credible earthquake magnitude

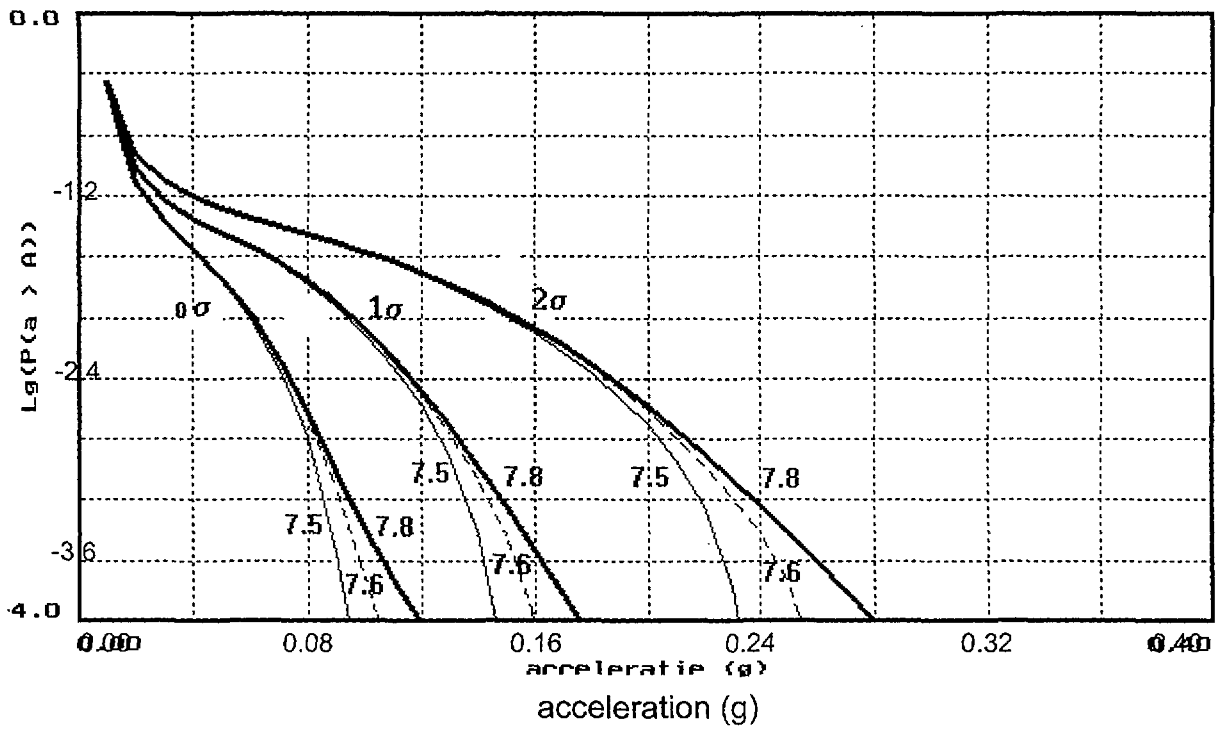

Figure 2.3 Seismic Hazard Curves for Cernavoda NPP Site for medium value: 120 Km depth and 190 Km epicentrum distance

3. ANALYSIS OF VRANCEA FOCUS ACTIVITY APPLYING THE AUTOREGRESSIVE TIME SERIES

Analyzing the seismic history of **Vrancea** focus, for the period **984-1900** it was found that there were large time-intervals in which no historical information were available. The largest time-interval corves **120** years **(1327-1446)** and makes the time series non - homogenous and thus no analysis was possible for that period in the first stage [**Ref. 6**].

The existing data, starting with the year **1900** by now, are quite homogenous and they can be applied in the analysis for that period.

Based on Auto-Regressive method, the analysis of the focus activity includes the following steps:

I. Determination and elimination from the time-series of the mean and all periodical components;

II. Determination of AR model parameters;

III Selection of AR model;

IV Prediction of events;

Here below there is a brief description of each step above.

I. Determination and elimination from time series of the mean and periodic components

The mean component of the time series is determined as an arithmetic mean of the time series and an elimination of the arithmetic mean is made for each element of the time series.

Determination of the all periodic components of the remain series, both as periods and values, is a very important stage and that is why several determination methods are applied.

a) *Determination of the period components by means of auto-correlation function*

In order to point out the periods, the auto correlation function was applied both to the initial series and to the resulted function until the periodic components became evident.

After **5** sequential applications, the component was obtained as per the **Figure 3.1** where two components are evidenced: the **2** years and the **13** years component.

b) *Determination of the periodic component using **Fourier** analysis*

Fourier analysis is a method to determine the periodic character of a time series by the detection of the periodic components.

By the application of **Fourier** transform, the existence of some components became quite obvious: **2**, **31** and **46** years. The periodic components with period grater than about 10 - 20 years (for a time-series of **93** records) are affected by computational errors and should be re-confirmed by other methods.

c) *Determination of the periodic components using a numeric method*

The numeric method determines the periods of components by the arrangement, as a table, of the time series as well as by the creation of a sub-series of constant lengths, subseries resulted

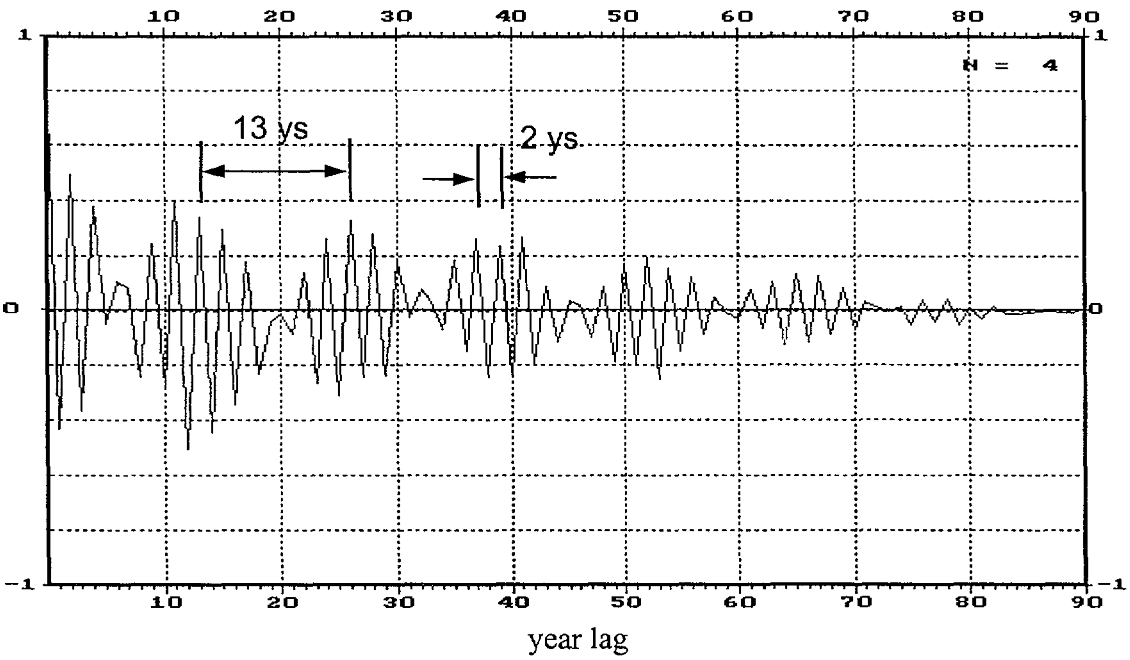

Fig 3.1 Auto-correlation function applied to the time series

from the division of the initial series by a number encompassed between **1** and the series length and the numeric processing of the time-series so obtained [**Ref.** 3].

The following periodic components were evidenced: **13, 27, 31, 41, 43** and **45** years. Large periodic components may have errors because the applied time-series has a relatively small number of events.

In case of a time series with **93** records (the case herewith), with components period larger then **30** years, there are sensible errors dependent on the increase of the detected period.

II. Determination of AR model parameters

The time-series remained after the elimination of the time-series mean and the periodic components are analyzed with **AR** model as follows.

In these models, a value **y** (earthquake magnitude value) at time **t** is produced as the sum of a linear regression on a finite number of previous values and an aleator residual component. [**Ref. 3, 4**].

If the regression is limited to **k** terms, then the equation:

$$y_t = \sum_{i=1}^{k} a_i y_{t-i} + \varepsilon_t \tag{3.1}$$

defines the so-called **Markov** model of order **k**. The a_i are autoregressive coefficients, and the residual $_t$, is an independent random variable uncorrelated with the y_{t-i} valus for $i = 1, 2, ..., k$.

For a first order scheme:

$$y_t = a_1 y_{t-1} + \varepsilon_t \tag{3.2}$$

and a_1 is given by the first auto-correlation coefficient, r_1, of the stationary series y_t. For the second order scheme:

$$y_t = a_1 y_{t-1} + a_2 y_{t-2} + \varepsilon_t \tag{3.3}$$

and a_1, a_2 are given by:

$$a_1 = \frac{r_1(1 - r_2)}{(1 - r_1^2)}; a_2 = \frac{(r_2 - r_1^2)}{(1 - r_1^2)} \tag{3.4}$$

where r_1, r_2 are the first and second-order auto-correlation coefficients of the stationary series y_t. The residuals $_t$ are found from:

$$\varepsilon_t = y_t - a_1 y_{t-1} \tag{3.5}$$

for the first-order scheme, and:

$$\varepsilon_t = y_t - a_1 y_{t-1} - a_2 y_{t-2} \tag{3.6}$$

for the second-order scheme.

III. Selection of AR model

An important problem of fitting a parametric model to a time series is how to choose the best order of approximation. For purely **AR** models it can be solved rather easily in most cases by applying the criteria [**Ref.** 4]:

$$AIC(k) = n \cdot \log \lambda^2(k) + 2k \tag{4}$$

for **k = 0, 1,...,k$_m$**,
where: **k** - the order of the current approximating model;
k$_m$ - maximum order which should be specified in advance;
n - the length of time-series;
^{2}**(k)** - the estimate of $_t$ for the current model of order **k**.

The optimal order is one for which **AIC(k)** attains its minimal value.

IV. Prediction of events.

In the alternatives subjected to analysis, the prediction on the seismic activity is performed using the average component, determined by the application of AR model [**Ref.** 4], to which the periodic components and the time-series mean are added. To those values, we can add a generated gaussian aleatory value of mean zero and the dispersion determined from the remained time - series (see paragraph II).

4. RESULTS

By the application of the above presented method, the seismic activity of **Vrancea** focus for a time-series encompassing the time-interval **1901- 1993** was analyzed under the following hypotheses:

- for the years in which data were not available, an earthquake having the magnitude equal to the minimum detectable value throughout the period, namely value **4**, was considered in the analyses;
- for the years in which more earthquakes existed, the earthquakes were considered equivalent to an earthquake which released an amount of energy equal to the sum of energies generated in that respective year.

Figures 4.1-4.2 show an unidimensional case, in which the annual maximum magnitude represents the time-series.

Moreover, a bidimensional case is presented herewith, a case in which the variables of time-series signify the time-interval between two subsequent earthquakes, namely, the magnitude of the earthquake occurred after each of these time-intervals. It is a case which, theoretically eliminates some lack of information in the initial data **(Figures 4.3 - 4.4)**.

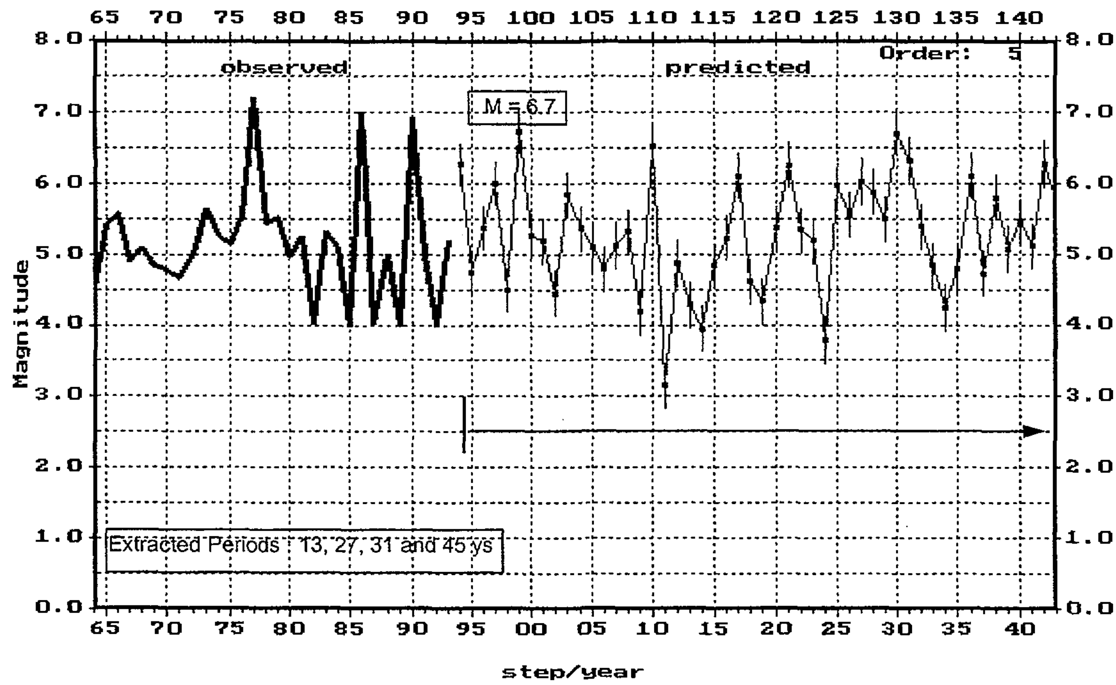

Fig. 4.1. Estimating preliminary analysis. Time - series: 1901 - 1993

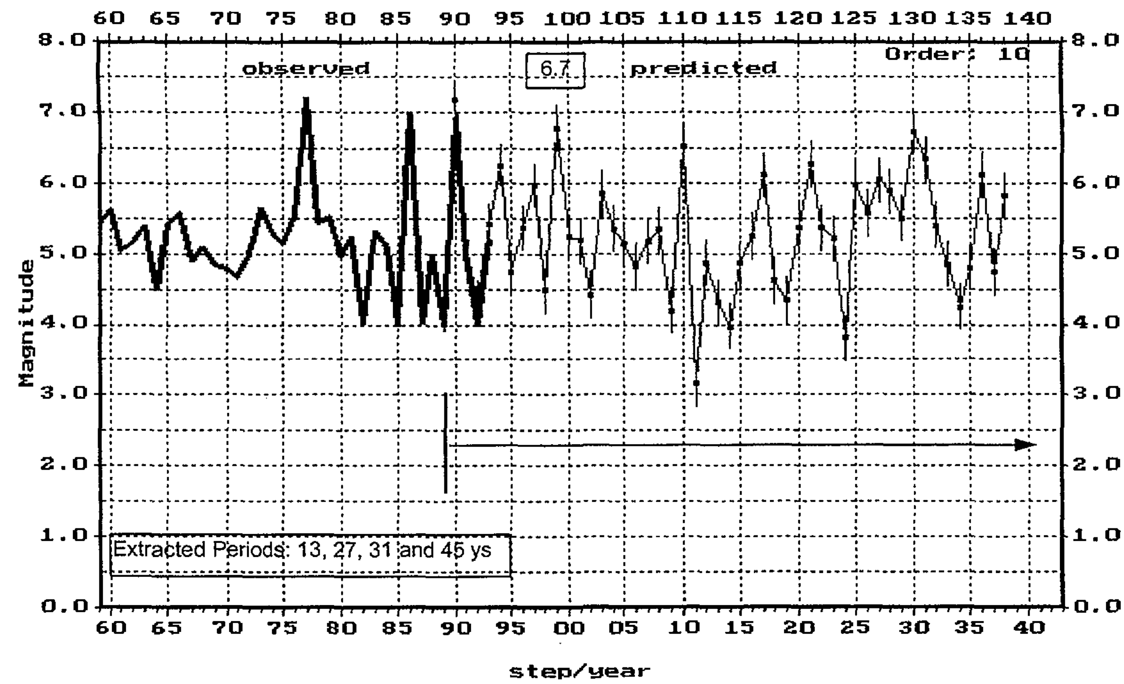

Fig. 4.2. Estimating preliminary analysis. Time - series: 1901 - 1988.

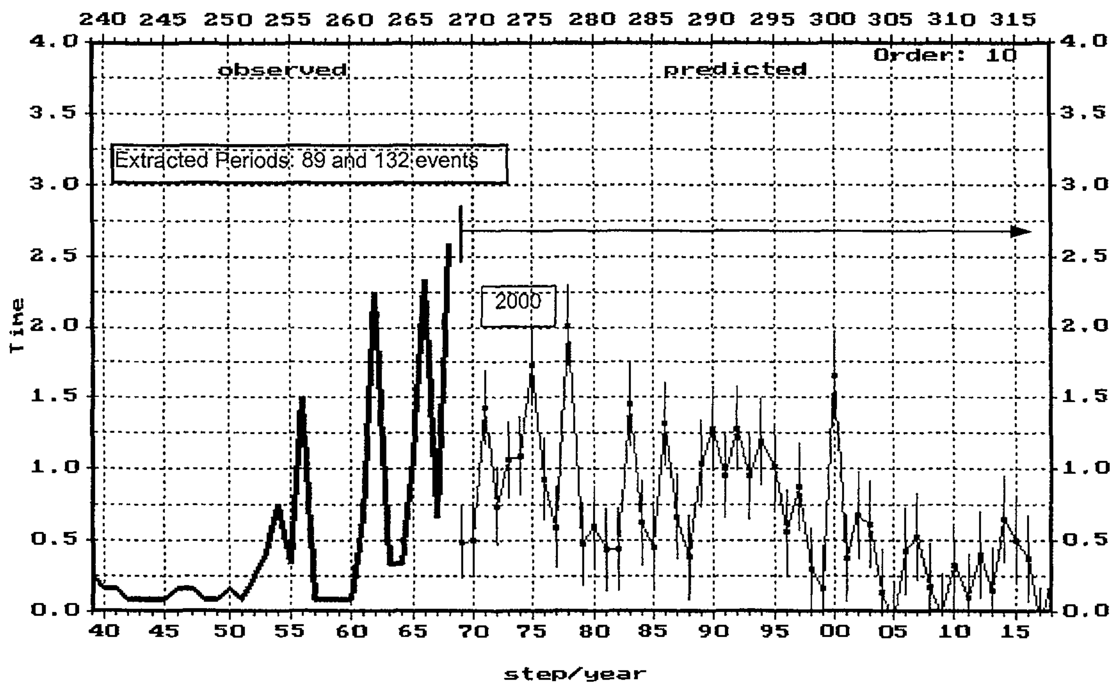

Fig. 4.3. Estimating preliminary analysis. Time - series: 1901 - 1993. Bidimensional case

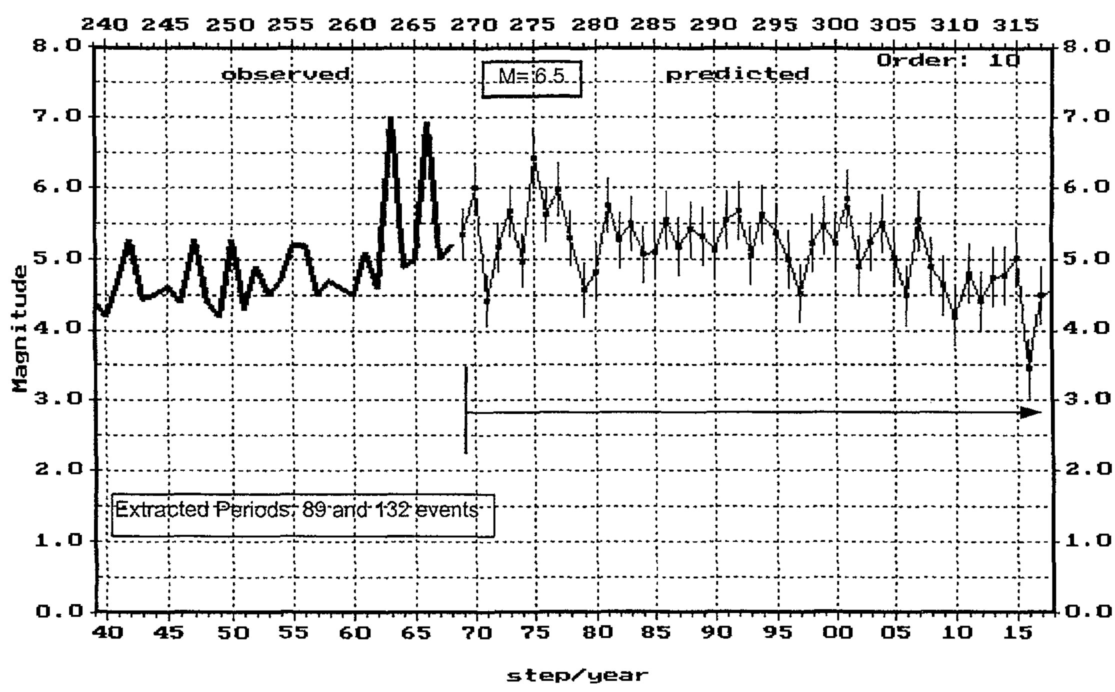

Fig. 4.4. Estimating preliminary analysis. Time - series: 1901 - 1993. Bidimensional case

5. CONCLUSIONS

This paper is a first attempt to predict the seismic activity of **Vrancea** focus based on time-series method.

Analyses for **Vrancea** focus were made using the time - series of the earthquake magnitude during the period **1901 - 1993** for which the estimation error is about **0.5** units of magnitude, according to some authors. Due to the lack of data, the analysis was done considering earthquakes of *equivalent* annual magnitudes in order to take into consideration the whole energy released during one year interval.

Following to those analyses, some conclusions could be drawn:

- **Vrancea** focus seismic activity is the result of the overlapping of some periodic components having as a basis, periodic components with the periods of about **13, 27, 31, 41, 43, 45** years;

- Although the duration of these periodic components as well as the magnitude of the components can be affected by a series of errors, such as: series length, computational method, etc., these components are quite clearly pointed out in the paper and their existence might be correlated with some phenomena related to the earth thermo - dynamics, earth tides, etc.

According to this first analysis, in **Vrancea** region, an earthquake of **6.7** magnitude might be generated in **1999** (from **Fig.4.1-4.2**); or an earthquake of **6.5** magnitude might be generated in **2000** (from **Fig.4.3-4.4**).

The magnitude average dispersion is about of **0.5 - 0.8** units of magnitude caused by the uncertainties of the initial input data, analysis method, etc.

These predictions are quite reliable because the earthquakes under investigations during **5** years (**1989 - 1993**, see **Fig.4.2**) have shown quite a coincidence with the predicted earthquakes.

Results obtained can be considered representative for the following reasons:

- the data used in the analyses are most complete by now, in the sense that small magnitude earthquakes, generated by **Vrancea** focus and available to us, have also been considered;

- the mathematical model allows processing of a large amount of information;

- the results, obtained for **Vrancea** focus by the simulation of a prognosis during **20 years** ago, showed a good fitness with the actual seismic activity of **Vrancea** focus from that data until today.

Finally, here are some proposals in order to update the **Vrancea** seismic activity data:

- continuation of researches by the above method, both by enlarging the time - series length, in the sense of considering a smaller time - interval of samples (i.e. **monthly** time - intervals) and / or by enlarging the period of research (e.q. starting with the year **1800**);

- filling in the years for which no information was available, with events generated by overlapping the periodic components established for full-data time periods;

- detailed bi-dimensional analysis using representative data;

- performance of similar analyses for at least **3** significant focus points on the **Earth** (possibly located in **USA, JAPAN** and **IRAN**) in order to determine whether those focus evidence deterministic periodic components and whether a part of them coincides with **Vrancea** focus periodic components. That would conform the hypothesis issued in this paper;

- correlation of time - duration and magnitude of periodic components with deterministic phenomena already known in the earth thermo - dynamics, earth tide dynamics forces, etc;

Based on the analyses performed, new hypotheses regarding the energy accumulation and release mechanism can be developed but that will be presented in a future stage.

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