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Seismic Hazard and Prognosis for Cernavoda NPP Site

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ABSTRACT

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.

The consideration of the seismic events, as independent events affecting the site, and the use of statistic methods with short internal analysis data to define some safety levels with very low annual occurrence probabilities (**10^{-4}**) may lead to some exaggerations of the seismic safety level. On the other hand the use of high values for the design seismic accelerations imposed by the seismic safety levels required by the hazard analysis, may lead to very costly and difficult to fulfill technical solutions that can make the plant operation more difficult and increase the maintenance costs.

1. INTRODUCTION

A large part of the seismic hazard curves used today in the seismic assessment of a NPP site is not representative for low annual probability values of occurrence (seismic hazard) because the hazard curve evidences a horizontal asymptote instead of a vertical one.

The seismic hazard curve should evidence a vertical asymptote because of the following two reasons:

- any actual focus has a maximum capacity to release energy which is not entirely directed to a given site; the results of it, is a maximum acceleration for very low probabilities, a maximum acceleration which is the vertical asymptote coordinate;
- there is a limited capacity of the foundation ground to transfer the maximum seismic acceleration from the bedrock to the free surface (i.e. increasing the accelerations on the bedrock, the total damping increases very much because of the non-linearity and exceeding of the ultimate strength).

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.

The method is useful for two purposes:

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

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

The paper evaluates the deterministic component using the available instrumental data (about the last one hundred years), generates the deterministic component backwards and fills in the lacking information periods with the generating component. Finally, within the seismic hazard analysis, the paper presents a comparison using original data base and the new modified database. Only the limited capacity of a focus (i.e. the maximum possible magnitude) has been considered herewith.

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 is 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.

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 then statistic approach 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.

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. 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. One kind of such interval covers **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: determination and elimination from the time-series of the mean and all periodical components, determination of AR model parameters, selection of AR model, 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 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 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 **97** 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 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, 46, 31** and **5** 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 **97** 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:

$$y_t = \sum_{i=1}^{k} a_i y_{t-i} + \varepsilon_t \qquad (1))$$

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

For a first order scheme:

$$y_t = a_1 y_{t-1} + \varepsilon_t \qquad (2).$$

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

$$y_t = a_1 y_{t-1} + a_2 y_{t-2} + \varepsilon_t \qquad (3))$$

and $\mathbf{a_1}$, $\mathbf{a_2}$ are given by:

$$a_1 = \frac{r_1(1 - r_2)}{(1 - r_1^2)}; a_2 = \frac{(r_2 - r_1^2)}{(1 - r_1^2)} \qquad (4))$$

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

$$\varepsilon_t = y_t - a_1 y_{t-1} \qquad (5))$$

for the first-order scheme, and:

$$\varepsilon_t = y_t - a_1 y_{t-1} - a_2 y_{t-2} \qquad (6))$$

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**]:

$$AIC(k) = n \cdot \log \lambda^2 (k) + 2k \qquad (7))$$

for $\mathbf{k = 0, 1, ..., k_m}$,

where: $\mathbf{k}$ - the order of the current approximating model;

$\mathbf{k_m}$ - maximum order which should be specified in advance;

$\mathbf{n}$ - the length of time-series;

$\boldsymbol{\lambda^2(k)}$ - the estimate of ε_t for the current model of order $\mathbf{k}$.

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

IV. Prediction and backwards generates events

The prediction and backwards generates events on the seismic activity can by 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.

The method is useful for two purposes:

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

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

3. TIME SERIES APLICATIONS

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.

Using these periodic components, we can translate them in the past in order to compare them with the historical records. To do this task we need a rich historical data base. In this case we have choosen **Lungu's Catalog [Ref. 9]**. In figures **1-5** the comparison between historical earthquake records developed by **Lungu [Ref. 9]** and the generated and translated deterministic component is shown.

4. 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.

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:

$$p(M,t) = 1 - e^{-\nu(M)t} \qquad (8)$$

where, **ν(M)** is the average annual number of earthquakes having the magnitude grater then **M**, given by the magnitude - frequency recurrence law.

5. CONCLUSION

This paper aimed to assess the seismic hazard for **Cernavoda NPP** has considered only **Vrancea** focus.

The analysis followed the following steps:

a) Based on the representative data on the period **1901-1997**, periodical components were determined and their value and duration has been evaluated.

The periodical components stated as important are: **13, 46, 31** and **5** years;

The historical data have been improved generating for the time interval **1000-1900** earthquakes on basis of the analyses made for the period **1901-1997.**

b) Seismic Hazard Analyses have been done with the following sets of data:

$\mathbf{B_1}$ – Earthquakes occurred during **1901–1997;**

$\mathbf{B_2}$ – Earthquakes occurred during **1000–1900;**

$\mathbf{B_3}$ – Earthquakes occurred during **1000–1997;**

$\mathbf{B_4}$ – Earthquakes occurred and generated during **1000–1997;**

Following to a preliminary hazard analysis on the **4** curves (see Figure **6**), it results that:

- Case $\mathbf{B_4}$ is situated between case $\mathbf{B_1}$ and $\mathbf{B_2}$;
- Case $\mathbf{B_2}$ and $\mathbf{B_3}$ is strongly affected by errors because of the large time intervals for which information is missing;
- Case $\mathbf{B_1}$ may be affected by errors because the member of high magnitude earthquakes is very low;
- Case $\mathbf{B_4}$ is considered most representatives because it eliminates the errors present with the previous case.

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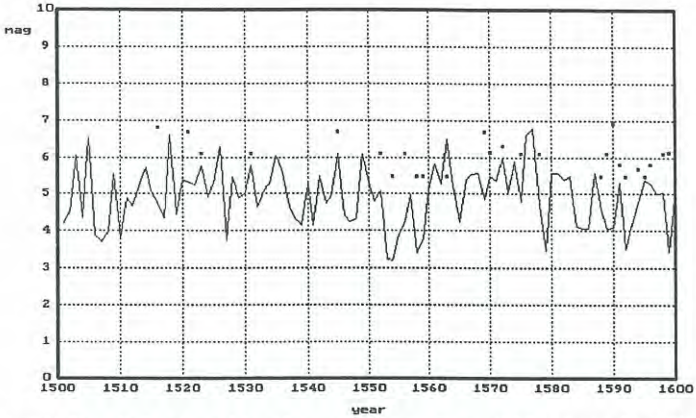

Fig. 1. Prediction and backward generation of Vrancea Activity.

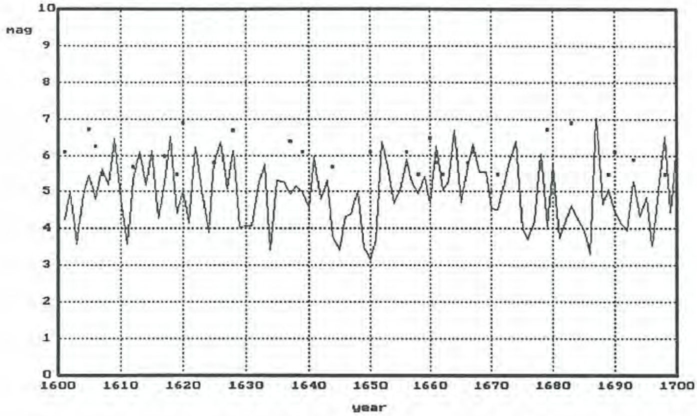

Fig. 2. Prediction and backward generation of Vrancea Activity.

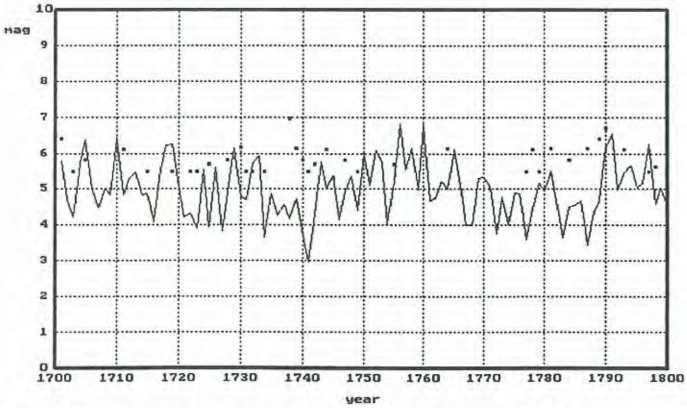

Fig. 3. Prediction and backward generation of Vrancea Activity.

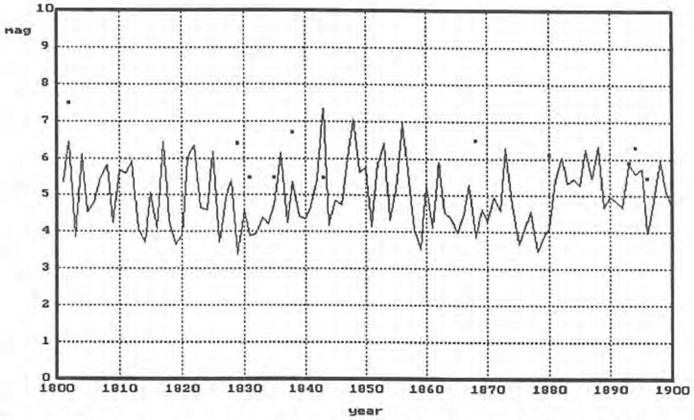

Fig. 4. Prediction and backward generation of Vrancea Activity.

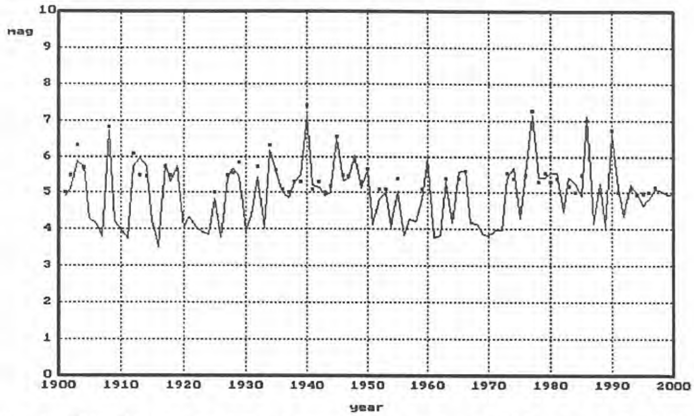

Fig. 5. Prediction and backward generation of Vrancea Activity.

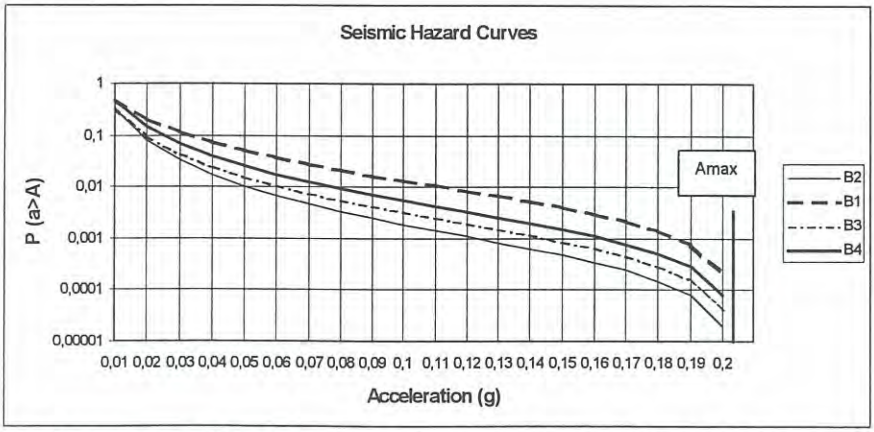

Fig. 6. Comparison of Seismic Hazard Curves for B1, B2, B3 and B4 Cases.