MULTILAYER CAPACITOR MODEL OF THE EARTH'S UPPER CRUST

B. Üstündağ[1] Ö. Kalenderli[2] H. Eyidoğan[3]

[1] *Computer Engineering Department, Electrical & Electronics Faculty*
Istanbul Technical University, 34469, Maslak, Istanbul, Turkey
[2] *Electrical Engineering Department, Electrical & Electronics Faculty*
Istanbul Technical University, 34469, Maslak, Istanbul, Turkey
[3] *Department of Geophysical Engineering, Faculty of Mines*
Istanbul Technical University, 34469, Maslak, Istanbul, Turkey

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ABSTRACT

In this study, an equivalent electric circuit model of Earth's upper crust is proposed to explain behavior of measurement patterns in an earthquake forecast system. A multi-layer capacitor model having active components that couples with the monopolar probe close to the surface was proposed to determine earthquake precursory patterns due to priory structural changes. Equivalent circuit model is developed for a) Dilatency process that is assumed to be a stress weakening reason b) External far force source that increases shear stress over the fault until sudden decrement before the earthquake. A data acquisition system consisting of 15 online measurement stations in Marmara region and a data processing center has been established three years ago. Anomalies which can be easily distinguished from regular daily behavior of the signal patterns were observed at 65±5% of the earthquakes with the magnitude greater than 4 and close less than 150 kilometers to the nearest station.

1. INTRODUCTION

People originating from different cultures have conducted their earthquake priory natural observations after several major earthquakes all over the world. Although some of them are thought to be depending on such factors as religion, education level and social background of the society, investigations have shown that some differentiations assumed to be precursory events of the nature have been commonly noticed independent of cultural factors [1]. Survivors had reported lightning spirits before the Kocaeli Earthquake in 17th August 1999 and a spark over the fault line above the sea and land during the occurrence of the earthquake. Unusual behavior of some animals were recorded by the security cameras just before the earthquake. Some people informed that their watches had stopped without any technical reason a few days before the earthquake and those problems disappeared after the earthquake. These observations led us towards one of the major measurable precursor of the earthquakes that might be the change in electric field close to the surface since,

a) battery powered watches have quartz crystals and piezoelectric property is reciprocal [2, 3, 4],
b) some gases locally lightens because of electric discharge due to impulsive electric field strength inside the atmosphere,
c) some hormonal levels, including serotonin, is affected by the electric field change where the serotonin is a behavior affecting hormone in animals [5],
d) and it has been shown by laboratory experiments that long animals such as snake tends to stay vertical to the electric fields in order to decrease the potential difference on its body [1, 6, 7].

It is known that electric potential variation over a standard cubic rock sample is directly proportional to the stress change ($d\sigma/dt$) under time varying mechanical load [8, 9] due to piezoelectricity and change of dielectric properties.

A monopolar probe system that is used for precision measurement of electric field variations [10] assumed to be related to earthquake precursory electromechanical changes. Some earthquake occurrence models and the electric circuit equivalent of the upper crust structure take place in section 2. Anomaly pattern examples correlating to some earthquakes are also shown for the analogy between the expected patterns due to proposed models and the real data.

Block diagram of the monopolar electric field measurement system used for data acquisition, that the proposed models are developed for, is shown in figure 1.

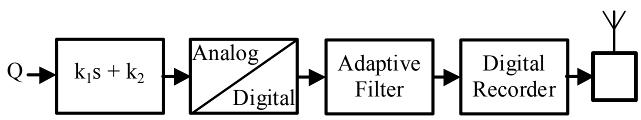

Figure 1. Block diagram of measurement and data acquisition system.

2. EXPLANATORY MODEL FOR DIFFERENT TYPE OF ANOMALIES

Unfortunately, structural complexity increases at the regions relatively close to the surface of the Earth's upper crust. Because of the structural uncertainties, three different models, which cover the most encountered cases, are proposed for the evaluation of real data and approximate determination of the parameters. These proposed explanatory models are used for characteristic classification of the anomalies. On the other hand, variations and cooperative usage of these simplified models may take role in more realistic explanations.

2.1 Multilayer capacitor model and liquid dilatency

Charged sphere approach for the Earth has been used for understanding the placement of the monopolar electric field probe here. Let the depth of a probable earthquake be $d_{hypocenter}$. Since $d_{hypocenter}/r_{earth} << 1$ parallel plate equivalent circuit can be used for multilayer capacitor approach instead of spherical layers. This approach also gives the ability of adding regional parameters that can probably be used in seismo-tectonic analysis using the data from the stations distributed over the surface. The parameters seen in the models (figure 2 and figure 3) are as follows,

- ε_a is the dielectric coefficient of the air,
- ε_1 is dielectric coefficient of the sedimentary layer,
- $\varepsilon_{2,3}$ is dielectric coefficient of upper crustal granitic layer,
- R_s represents equivalent reservoir output resistance of the leakages, which determines the time constant of liquid dilatency,
- C_4 couples the circuit model to the lower layers of the crust where piezo electricity is negligible beside the affects such as pyroelectricity,
- U_p is the local stress dependent equivalent voltage source,
- q_E is the equivalent charge source representing affect of the unconsidered lower layers.

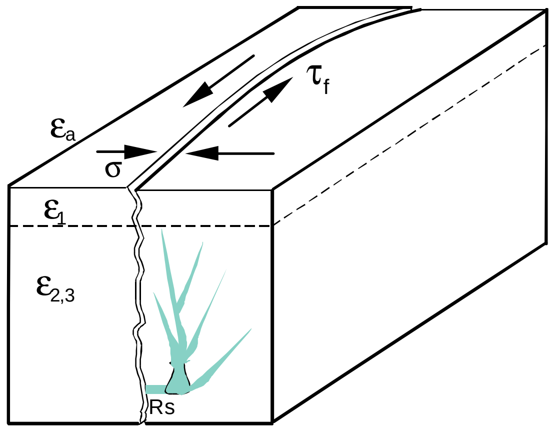

Figure 2. The elements of earthquake occurrence model having dielectric and mechanical parameters including liquid dilatency.

The rectangular block in the model is exposed to the shear force τ_f that causes mechanical energy cumulation at either horizontal or the vertical directions. Raise amount of the charged energy is generally expressed in terms of equivalent yearly displacement [centimeters] in Earth sciences. σ is the normal stress that is a factor bonding the fault surface and it is also used in explanation of friction and instability models [11].

Equivalent electric circuit model of the upper crust that is used for explanation of the effect of dilatency on surface electric fields is shown in figure 3. The proposed circuit model is as multilayer capacitor system having stress dependent voltage source. Upper crustal granitic layer is reduced into two different layers having pure piezoelectric material and non-piezoelectric material for the simplicity of the simulations. Dielectric coefficient $\varepsilon_{2,3}$ is replaced by ε_2 and ε_3 respectively. ε_3 represents the dielectric coefficient of the layer consisting of pure piezoelectric material.

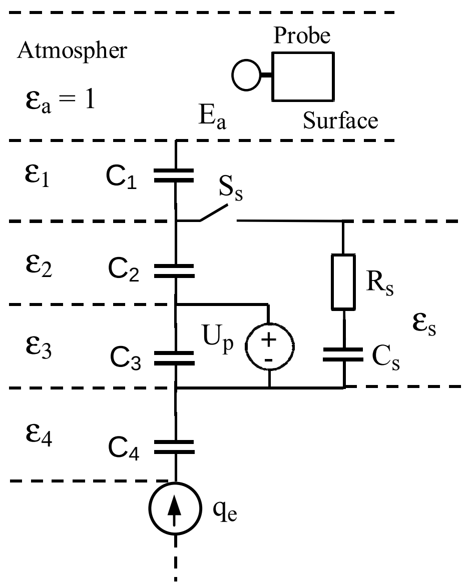

Figure 3. Equivalent circuit model of dilatency.

Capacity of each layer in an n-layer capacitive system is,

$$C_1 = \frac{\varepsilon_1 \cdot S}{a_1} \qquad C_2 = \frac{\varepsilon_2 \cdot S}{a_2} \qquad \dots \qquad C_n = \frac{\varepsilon_n \cdot S}{a_n} \tag{1}$$

where S is the surface and a_n is the thickness of the n^{th} layer [12].

$$C = \frac{S}{\frac{\varepsilon_1}{a_1} + \frac{\varepsilon_2}{a_2} + \dots + \frac{\varepsilon_n}{a_n}} \tag{2}$$

Since the charge of each layer is equivalent

$$Q = C \cdot U = C_1 U_1 = C_2 U_2 = \dots = C_n U_n \tag{3}$$

voltage drop over the layer can be expressed as,

$$U_k = \frac{a_k}{\varepsilon_k}\frac{U}{A} \qquad k = 1, 2, ..., n \tag{4}$$

where,

$$A = \frac{\varepsilon_1}{a_1} + \frac{\varepsilon_2}{a_2} + ... + \frac{\varepsilon_n}{a_n} \tag{5}$$

and the electric field strength inside each layer is,

$$E_k = \frac{U}{\varepsilon_k A} \qquad k = 1, 2, ..., n \tag{6}$$

which means that electric field strength is independent from the surface and varies with dielectric coefficient if we assume that the electric potential is constant.

$$E_a = \frac{E_3\, \varepsilon_3}{\varepsilon_a} \tag{7}$$

stress dependent voltage source due to piezoelectricity can be expressed as,

$$U_p = 0.25\, l\, p\, d\ [V] \tag{8}$$

where P is σ oriented pressure [bar], d is the anisotropic mineral ratio and l is average fault gouge. 0.25 is valid only under the assumption that stress sensitivity of all piezoelectric minerals are same as quartz for the simplicity.

$$E_p = \frac{Up}{l} = 0.25 \cdot p \cdot d\ [V/m] \tag{9}$$

Since pure piezoelectric portion is represented with a different capacitive layer d ratio is 1 for C_4. If the change of pressure due to stress drop during the stress weakening and earthquake process is p = 200 bars as an example then the change in Electric field strength will be

$$E_a = \frac{50 \cdot 5}{1} = 250\ V/m$$

without liquid dilatency.

In case of liquid dilatency, change in E_a will also be a function of change in voltage Up because of the new shunt capacitor representing the dielectric coefficient of the fluid. The dilatency process begins with the switch Ss in the equivalent circuit and the time constant is determined by $\tau = R_s C_s$. The expected behavior of E_a will be $\Delta E \cdot \exp(-t/\tau)$ which is observed in many record examples before the earthquakes. Although the volume filled by the fluid inside the crack is relatively low, change in E_a is still effective since $\varepsilon_s = 81$ which is much greater than $\varepsilon_3 = 4$ and $\varepsilon_4 = 5$.

2.2 Preliminary cracks and dry dilatency

Alternatively dry dilatency model is proposed for the explanation of pulse type anomalies observed 12...48 hours prior to earthquakes.

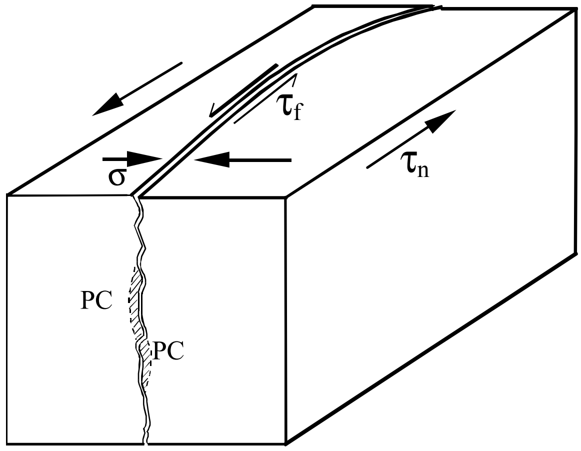

Figure 4. The elements of earthquake occurrence model for dry dilatency and elastic brittle crack approach.

The regions marked as PC (figure 4) represent the weakening zone where preliminary cracks may occur due to inhomogeneity of the fault. Two of the probably related record examples are shown in figure 5 and figure 6.

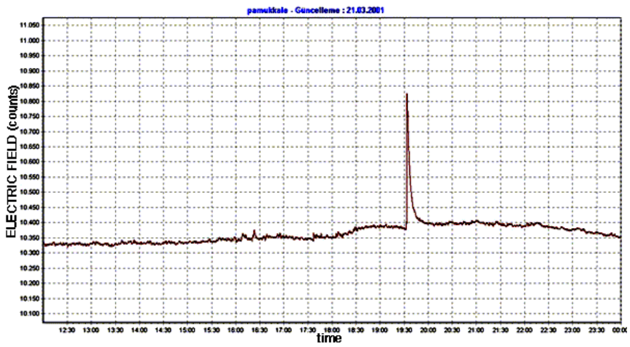

Figure 5. 37 hours before the Earthquake in Afyon Mb4.8 (March 21st, 2001).

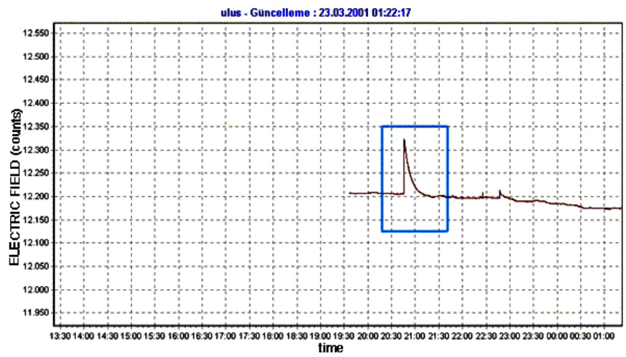

Figure 6. 40 hours before the Earthquake in Istanbul Mb3.9 (March 23rd, 2001).

Electromagnetic model of the geological fault [13] was described by Ikeya as,

$$\frac{dq}{dt} = -\alpha\frac{d\sigma}{dt} - \frac{q}{\varepsilon\rho} \tag{10}$$

where q denotes charge density. σ, α, ε and ρ are stress, charge generation constant, permittivity and the electric resistivity respectively. If time constant of the stress release is τ then the pulsed charge rate respecting to release of Δσ will be [13],

$$q(t) = \alpha\,\Delta\sigma\frac{\varepsilon\rho}{\tau-\varepsilon}(e^{-t/\tau} - e^{-t/\varepsilon\rho}) \tag{11}$$

where the character of the in time domain is similar to many observations such as shown in figure 5 and figure 6.

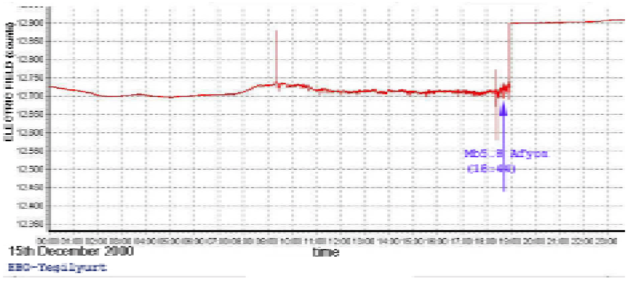

Figure 7. An example for a probable stress weakening process prior to the earthquake in Afyon Mb5.8 (December 15th, 2000).

2.3 Elastic brittle crack model

Another approach to earthquake occurrence is the case that there is not any kind of dilatency. The far field shear force τ_n (figure 4) introduced by tectonic loads drives the stress over the fault τ_f . Earthquake occurs in the strain level 10^{-6}...10^{-4} depending on the earth material properties. This limit is given as,

$$\sigma\cdot\mu \le \tau_f \tag{12}$$

where μ is the average static fault friction. Due to brittle behavior of the material, there should be decrement in stress σ just before the earthquake although strain continues to build up. In some fault models instability of the fault slip is controlled by the friction [11] and the equivalent spring element. Long term increment in electric field change that is followed by a sudden decrement met in some records can possibly be explained as elasto-plastic phenomena.

Acquired data patterns of 15 stations in Marmara Region are applied to the input of an artificial self-learning neural network mechanism [14]. The patterns are classified with respect to the precursory time interval, magnitude and the location of the occurred earthquakes by the network. 3 outputs of the network (distance, time interval, magnitude) tend to go 1 as the similar anomalies are received by the system. This training mechanism is used as a long-term alternative data evaluation method in earthquake forecast.

3. CONCLUSIONS

Proposed multi-layer capacitor model of the crust indicates that change of dielectric features due to structural changes, such as liquid dilatency, requires a change in the electric field at the surface. Amount of the variation is locally independent from the area. Similarity of the patterns between the model based simulations using approximate parameters and the real data based patterns beside the relatively high correlation between the anomalies and the earthquakes gives hope for the progress of earthquake forecast in future. Although piezoelectric property disappears above Curie temperature (approximately 10 km of depth is the limit), there still exist correlating anomalies before the earthquakes with in the depth level 10...20 km. Rigid load share between the deeper and upper levels of the fault block due to it's structural integrity is one of the possible reasons. On line station data and the previously collected data can be reached through the Internet site of the project http://www.deprem.cs.itu.edu.tr. Low depth of the major earthquakes in Turkey is an advantage for monopolar electric field measurement. It is possible to modify equivalent circuit model of the multi-layer capacitor approach with some additional parameters.

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