EARTHQUAKE PREDICTION USING A NEW MONOPOLAR ELECTRIC FIELD PROBE

Abstract

A new monopolar electric field probe is designed for precise measurement of change in electrostatic displacement close to the surface regarding to change in fault stress. A multilayer capacitor model having active components that couples with the monopolar probe in the surface is proposed to determine precursory patterns. 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.

Anisotropic minerals, mainly the SiO_2 are highly common in nature and they have the property of piezoelectric effect. It is known that electric potential variation over a standard cubic test sample is directly proportional to the stress change (dδ/dt) under time varying mechanical load. There had been some researches on earthquake prediction including VAN Method depending on this principle. In VAN method, electrical potential is measured by means of voltage difference between the electrodes inserted inside the soil at different locations. An advantage of monopolar displacement measurement contrary to VAN method is lower and filterable noise level since differential voltage is not only dependent on regional stress change but also it varies by changes in soil properties such as humidity, impedance, and natural battery affects.

A data acquisition system consisting of 11 online measurement stations in Marmara region (northwestern Turkey) and a data processing center has been established two years ago. Anomalies which can be easily distinguished from regular daily behavior of the signal patterns were observed at 65% of the earthquakes with the magnitude greater than 4 and close less than 150kilometers to the nearest station.

1. Introduction

There have been many research activities on prediction of approximate time and the epicenters of probable earthquakes. Some of these researches depend on evaluation of physical changes on earth surface. Widely worked parameters are change in soil resistivity, spectral analysis of transmitted electromagnetic signals inside the ground, electric potential change between probe points, change in radon emission rate, temperature change in thermal spring waters, water level change inside the wells, measurement of long term movement of terrestrial points by GPS, temporal and spatial changes in background seismicity, observation of behavior of the biological beings [1] and measurement of acoustic emission [2].

Survivors reported lightening spirits before the Kocaeli earthquake in 17th August 1999 and the spark over the fault line above the sea and land during the earthquake. Unusual behavior of some animals were recorded by the security cameras just before the earthquake. Some people determined 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) the watches had quartz crystals and piezoelectric property is reciprocal[3],[4] (b) some gases locally lightens because of electric discharge due to electric field strength inside the atmosphere (c) serotonin change is determined due to electric field change under the laboratory conditions where the serotonin is a behavior affecting hormone in animals [1] (d) and it is known that long animals such as snake tends to stay vertical to the electric fields in order to decrease the potential difference on its body [5][6].

Anisotropic minerals, mainly the quartz highly common in nature and they have the property of piezoelectric effect. It is known that electric potential variation over a standard cubic test sample is directly proportional to the stress change (dδ/dt) under time varying mechanical load [7][8]. There had been some researches on earthquake prediction including VAN Method depending on this principle. Electrical potential is being measured by means of voltage difference between the electrodes inserted inside the soil at different locations [9]. Electrical voltage does not only depend on regional stress change but also varies by changes in soil properties such as humidity, chemical reactions, impedance, and natural battery effects. This is a disadvantage of differential electric potential measurement inside the soil.

In this study, quasistatic waves and change in ultra low frequency component of electric fields are evaluated by using a specially designed monopolar probe. Variations of electric charge in the air close to the surface of the earth is measured and stored for evaluation of short and mid term earthquake prediction.

The monopolar probe [10] and measurement method is explained in section 2. Some earthquake occurrence models and the electric circuit equivalent of the upper crustal structure take place in section 3. 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.

2. Monopolar Electric Field Measurement

One part of the sensor mechanism is the Earth that is coupled to the monopolar electrode through air in the proposed method. Maximum electric field strength occurs at the surface of any sphere that is loaded by a voltage source (figure 1) [11]. The electric field decreases inverse square proportional to the distance from the surface of the source. This is also valid for the earth as a globe since the upper atmosphere consists of negative ions.

A high sensitive monopolar electric charge probe has been developed which will be installed close to the surface of the earth for this reason. We assume that change in charge induction at the probe should be related to the change in regional resultant stress as an electric potential source. Although there also exist atmospherical electric field changes as noise, which can be filtered since the frequency range is much higher than what is assumed to be proportional to the change in regional stress. On the other hand superposition of the attenuated electric field changes from further regions should be considered. These two facts require vectoral measurement using a group of stations and adaptive filtering for the removal of the atmospheric noises.

The system consists of a spherical capacity as electric charge collector, reverse connected MOSFET circuit as monopolar charge/bipolar voltage converter, indicator device for amplification, analog to digital conversion, signal processing, data acquisition and a personal computer for pattern analysis. Monopolar electric charge is collected on the conductor surface of the sphere with the diameter of 40mm. Collected charge is conducted via a high voltage cable to the reverse connected MOSFET 's (Metal Oxide Field Effect Transistor) gate with a high valued resistor, which are placed in a dielectric box. The cover of the box has a hole for high voltage cable at the center. The MOSFET is especially worked in high gain region, which is different from regular applications and components' physical sizes, and positions are arranged so that the leakage would be minimum as the measurement accuracy is in 10^{-14} Coulomb level.

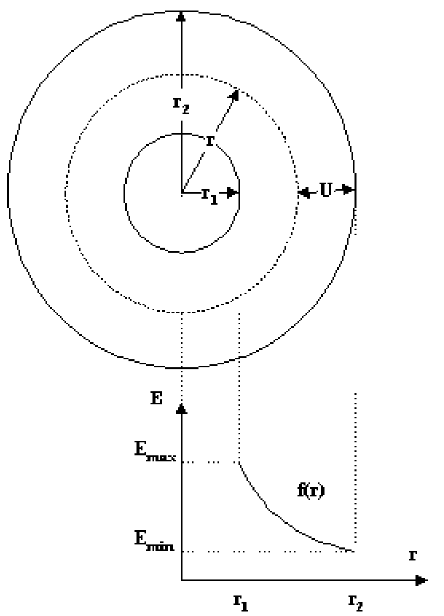


Figure 1. Electric field change with respect to distance (r-r_1)outside the charged sphere

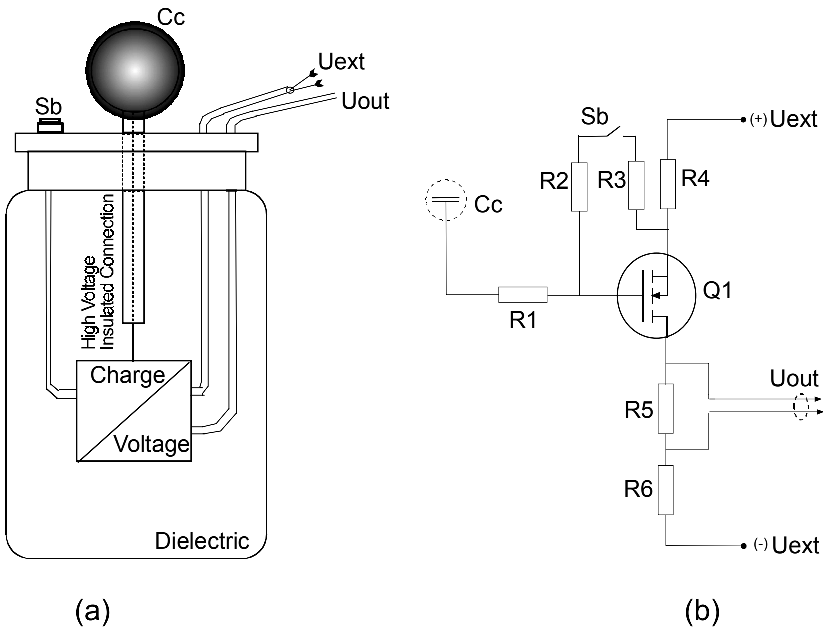


Figure 2. a) Monopolar electric charge measurement probe
b) Electric charge / Bipolar voltage converter

Collected charge amount from the air is calculated with respect to Gauss Law,

$$Q = \oint D ds \tag{1}$$

Since the relation between the electric field strength and dielectric displacement is,

$$D = \varepsilon \cdot E \tag{2}$$

the amount of charge collected by the probe's sphere is,

$$Q = 4\pi \cdot r^2 \cdot \varepsilon \cdot E \tag{3}$$

where r is the radius of the sphere on the probe. Drain current of a MOSFET (Metal Oxide Field Effect Transistor) is a function of gate-source voltage V_{GS} which is determined by the gate charge driven by the electrode Cc. In this case the output voltage related to Q is,

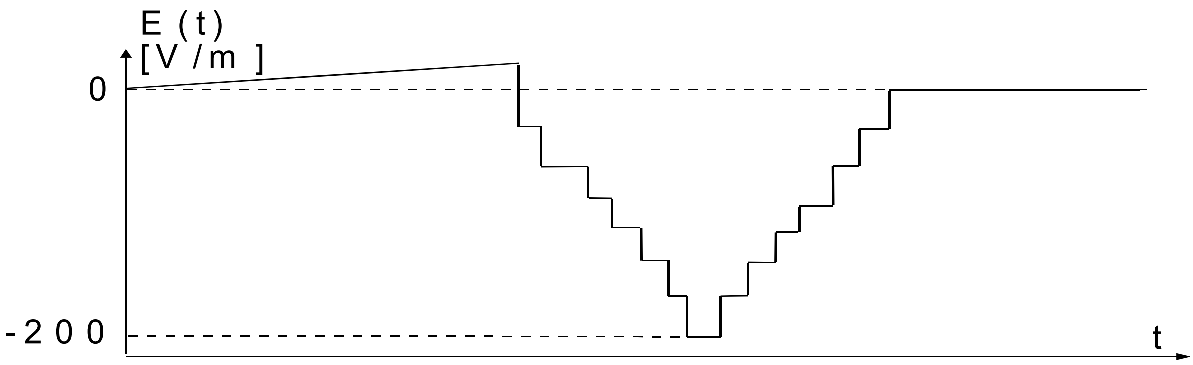
$$V_{out} = R_5 \cdot I_D = R_5 \cdot f(V_{GS}) = R_5 \cdot f(Q) \quad (4)$$

where R5 is the measurement resistance and the function f(Q) is determined by the transistor parameters given in the data sheets. Dynamic behavior of the charge/bipolar voltage converter is in the form of

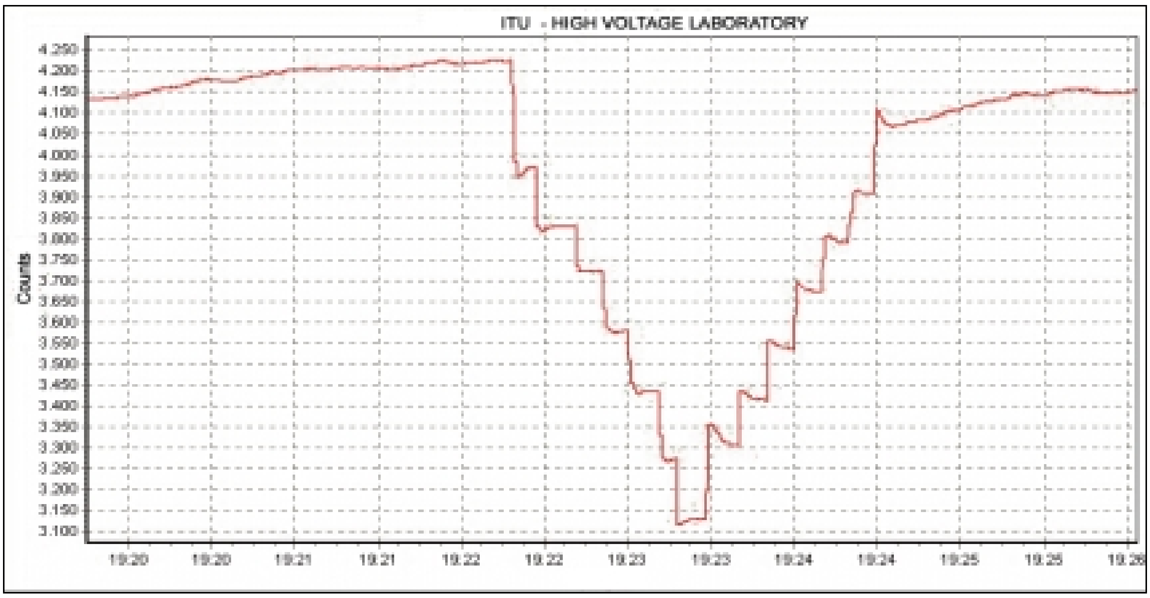
$$V_{out}(t) = k_1 \frac{dE(t)}{dt} + k_2 \cdot E(t) \quad (5)$$

where $k_1 = 0.05$ and $k_2 = 0.186$. Transfer function of the monopolar probe can be written as,

$$T(s) = k_1 s + k_2 \quad (6)$$



(a)



(b)

Figure 3. a) Change of electric field strength during lab test
b) Response of the monopolar measurement system with respect to change in electric field in (a) [output counts]

which means that steady state accuracy is 0,186 [counts/(V/m)]. It is clear that accuracy can easily be raised by enlarging the electrode (sphere) surface. Laboratory tests shown in figure 3 verifies the calculated transfer function T(s) with respect to the relation between the applied electric field pattern and the output data pattern.

3. Explanatory model for different type of anomalies

The proposed earthquake occurrence models given in this section provide the electric field strength input to the data acquisition system shown in figure 4 for the simulations. If the exact structure of the crustal had been known the only problem would be the determination of parameters.

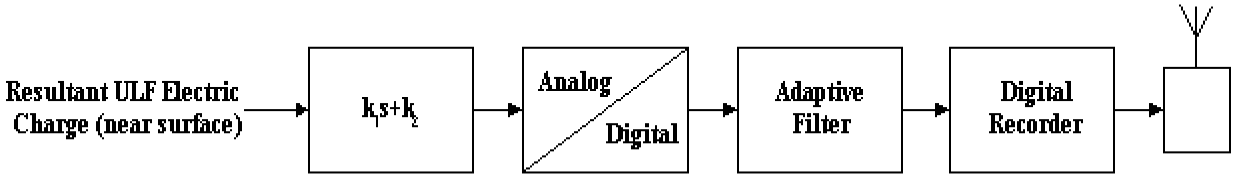


Figure 4. Block diagram of measurement and data acquisition system

Because of the structural uncertainties, three different models, which cover the most encountered cases, are used for the evaluation of real data and determination of the parameters.

Two of the many similar anomaly patterns that can easily be distinguished from the regular daily behavior are shown in figure 5 and figure 6, respectively. The model explained in 2.1 is used to explain these types of precursory patterns. Earthquakes happened at the minimum transition in both cases like many other records. The difference of the second example from the first one is the step up pattern coinciding the earthquake.

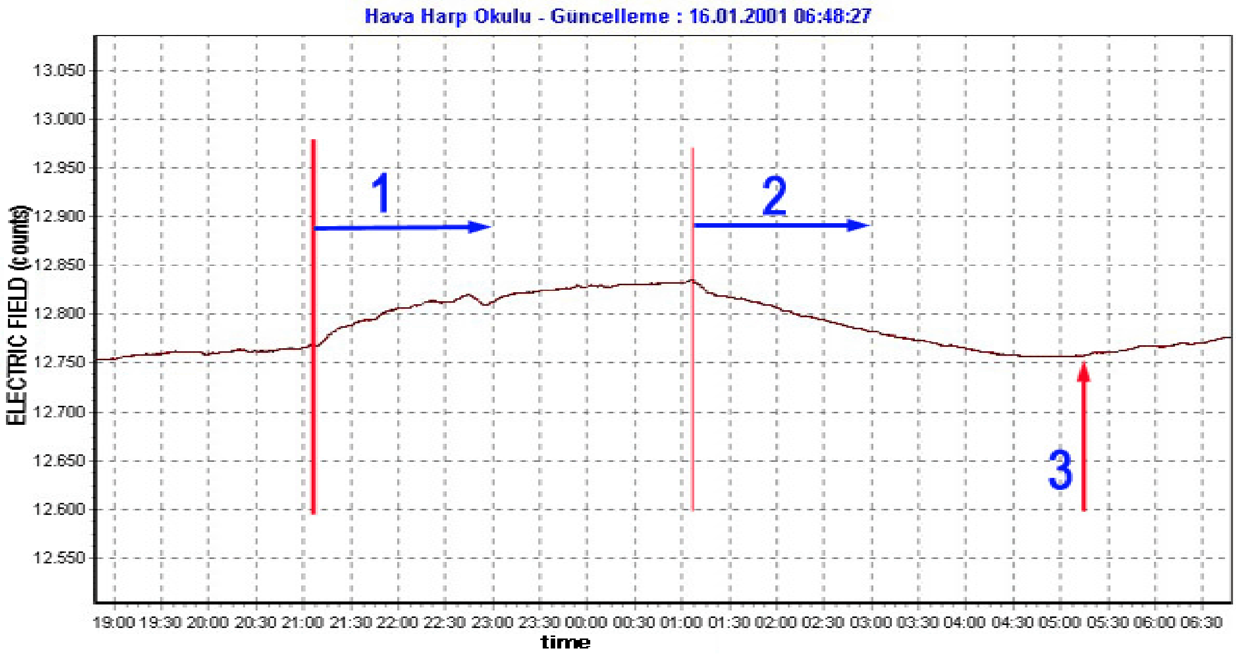


Figure 5. Change of electric field before an earthquake (red arrow) with magnitude 4.2 in 16th January 2001, Kartal-İstanbul

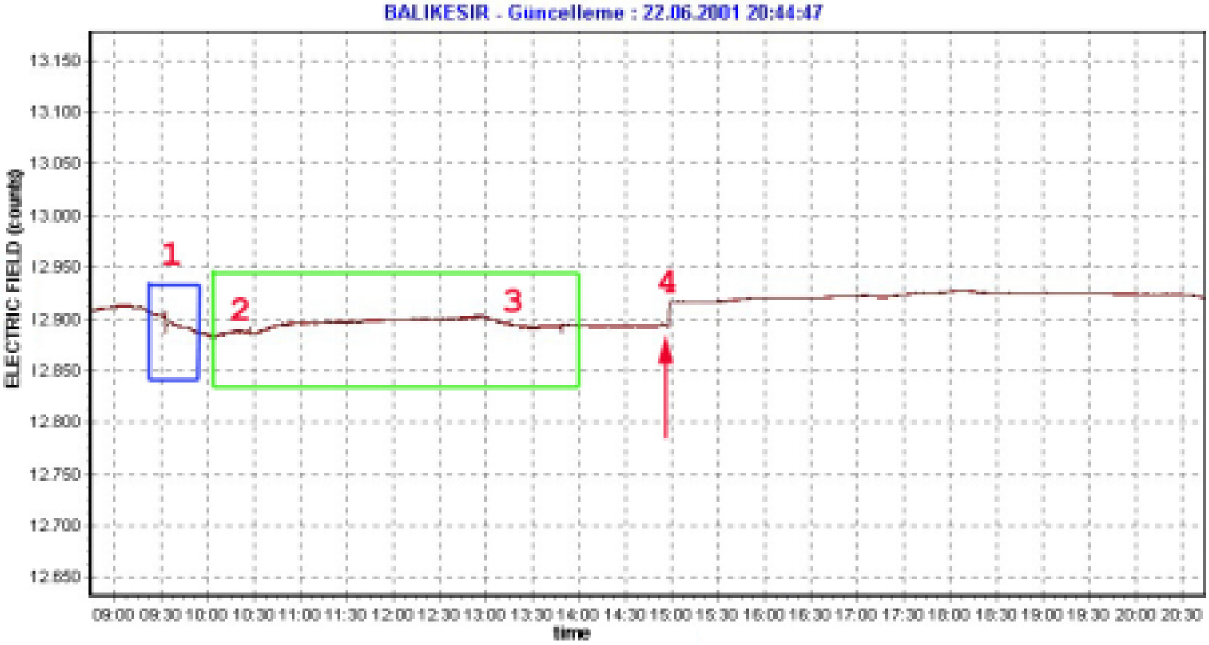


Figure 6. Change of electric field before an earthquake (red arrow) with magnitude 5.1 in 22nd June 2001, Balıkesir

3.1 Multilayer capacitor model and liquid dilatency

Charged sphere approach for the earth has been used for the placement of the monopolar electric field probe. 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 seismotectonic analysis using the data from the stations distributed over the surface. The parameters seen in the models (figure 7,8) are as follows,

ε_a dielectric coefficient of the air

ε_1 dielectric coefficient of the sedimentary layer

$\varepsilon_{2,3}$ dielectric coefficient of upper crustal granitic layer

Rs represents equivalent reservoir output resistance, which determines the time constant of liquid dilatency

C4 couples the circuit model to the lower crust where piezo electricity is negligible beside the affects such as pyroelectricity.

Up is the local stress dependent equivalent voltage source

q_E is the deep earth component

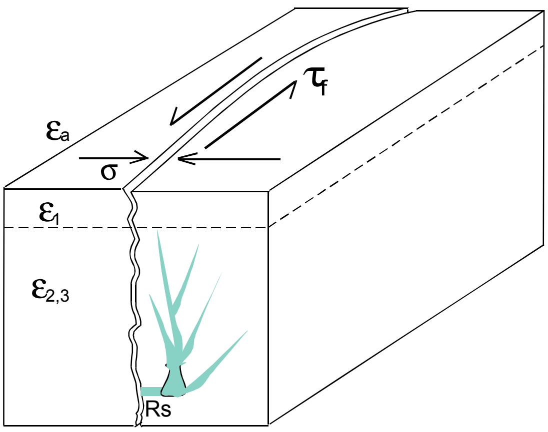


Figure 7. The elements of earthquake occurrence model having dielectric and mechanical parameters including liquid dilatency.

Crustal granitic layer is reduced into two different layers having pure piezoelectric material and non-piezoelectric material for the simplicity of simulation. 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.

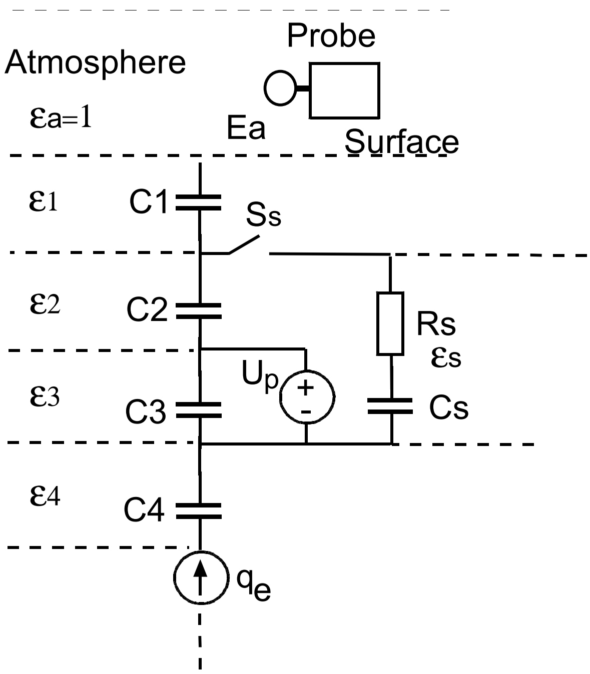


Figure 8. Equivalent circuit model of dilatency

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

$$C_1 = \frac{\varepsilon_1 \cdot S}{a_1}$$

$$C_2 = \frac{\varepsilon_2 \cdot S}{a_2} \tag{7}$$

....

$$C_n = \frac{\varepsilon_n \cdot S}{a_n}$$

where S is the surface and a_k is the thickness of the n^{th} layer.

$$C = \frac{S}{\frac{\varepsilon_1}{a_1} + \frac{\varepsilon_2}{a_2} + \ldots + \frac{\varepsilon_n}{a_n}} \tag{8}$$

Since the charge of each layer is equivalent

$$Q = C \cdot U = C_1 U_1 = C_2 U_2 = \ldots = C_n U_n \tag{9}$$

voltage drop over the layer can be expressed as,

$$U_k = \frac{a_k}{\varepsilon_k} \frac{U}{A} \qquad k = 1,2,\ldots,n \tag{10}$$

where,

$$A = \frac{\varepsilon_1}{a_1} + \frac{\varepsilon_2}{a_2} + \ldots + \frac{\varepsilon_n}{a_n} \tag{11}$$

and the electric field strength inside each layer is,

$$E_k = \frac{U}{\varepsilon_k A} \qquad k = 1,2,...,n \tag{12}$$

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.

$$E_a = \frac{E_3 \varepsilon_3}{\varepsilon_a} \tag{13}$$

stress dependent voltage source due to Piezo electricity can be expressed as,

$$Up = 0.25 \cdot l \cdot P \cdot d \ \text{[V]} \tag{14}$$

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

$$E_p = \frac{Up}{l} = 0.25 \cdot P \cdot d \ \text{[V/m]} \tag{15}$$

Since pure piezoelectric portion is represented with a different capacitive layer d ratio is 1 for C4. If the change of pressure due to stress drop during the stress weakening and earthquake process is P=200bars as an example then the change in Electric field strength will be

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

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 τ=RsCs. The expected behavior of Ea will be ΔEexp(-t/ τ) which is determined in many record examples before the earthquakes. Although the volume filled by the fluid inside the crack is relatively low, change in Ea is still effective since ε_s =81 which is much greater than ε_4=5 and ε_3 =4.

3.2 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.

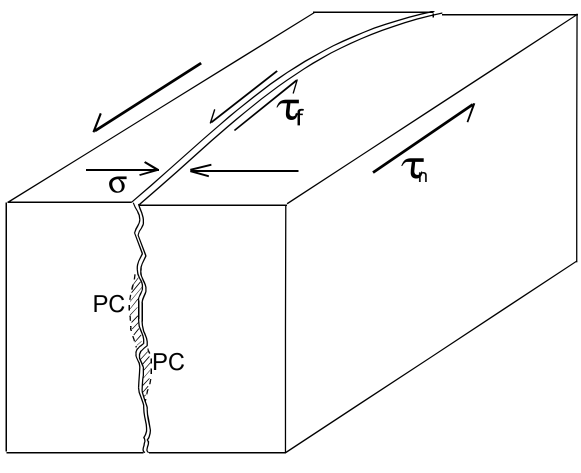


Figure 9. The elements of earthquake occurrence model for dry dilatency and elastic brittle crack approach.

The regions marked as PC (figure 9) represent the weakness zone where preliminary cracks may occur due to inhomogeneity of the fault. Two of the probably related record examples are shown in figure 10 and figure 11.

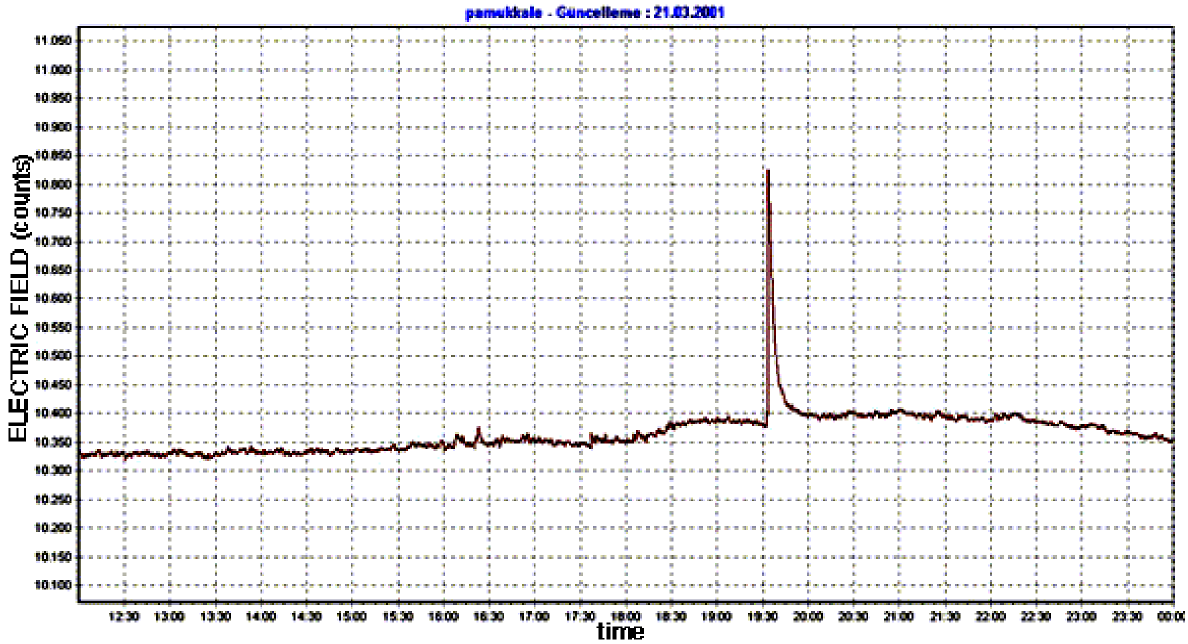


Figure 10. 37 hours before the Earthquake in Afyon Mb4.8 (March 21st, 2001).

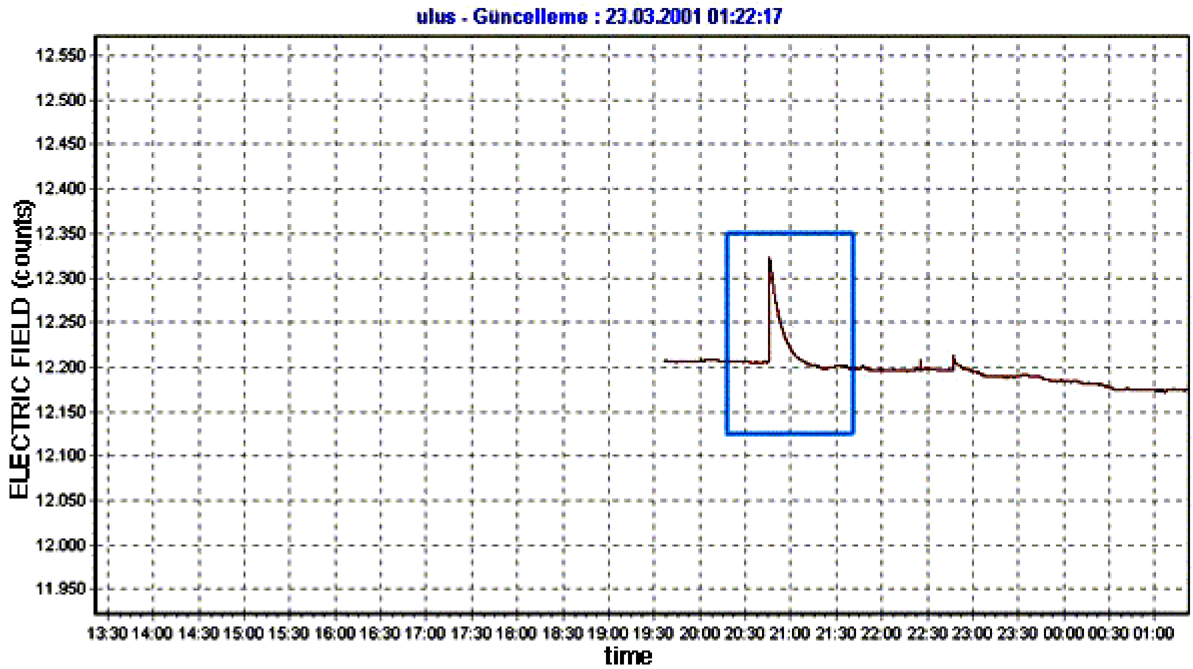


Figure 11. 40 hours before the Earthquake in Istanbul Mb3.8 (March 23rd, 2001).

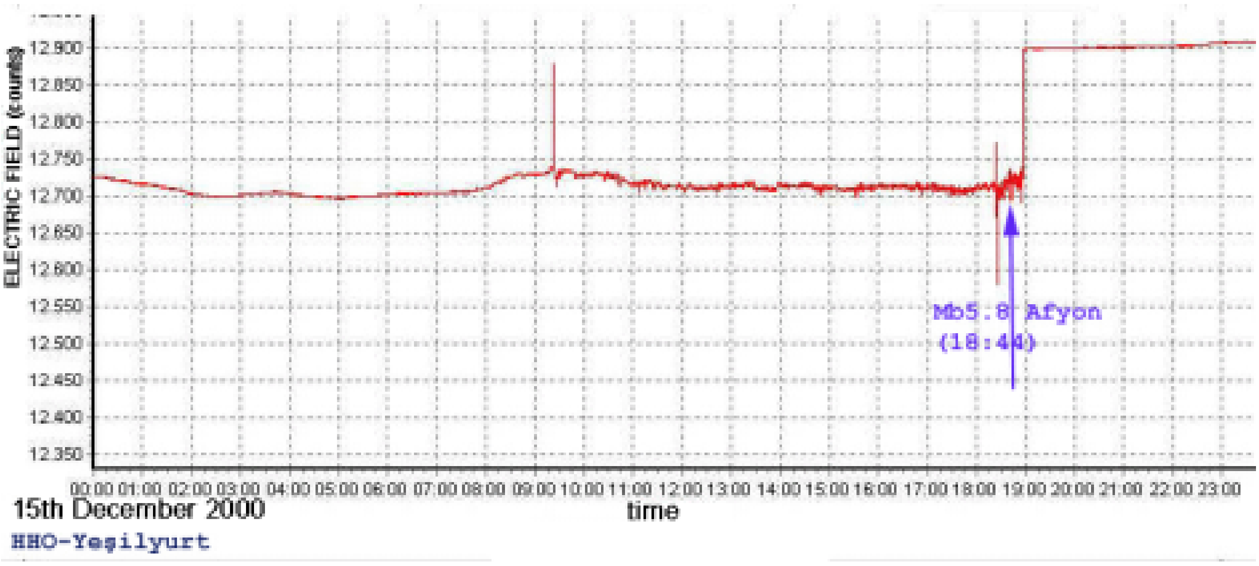


Figure 12. An example for a probable stress weakening process prior to the earthquake in Afyon Mb5.8 (December 15th, 2000).

3.3 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 9) 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,

$$\sigma \cdot \mu \leq \tau_f \qquad (14)$$

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 [12] 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.

4. Discussion

Although piezoelectric property disappears above Curie temperature (approximately 10km of depth is the limit), there still exist correlating anomalies before the earthquakes with in the depth level 10..20km. 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. Tidal effect is also determined in the long term harmonic analysis of the station records using discrete Fourier Transformation. The correlation ratio of the monopolar electric field pattern based anomalies to the earthquakes inside the project area is relatively high but there is still uncertainty in the relation between the magnitude of the occurred earthquakes and the properties of the patterns such as amplitude and time constant. Although the greatest change in electric field, after the beginning of the project, is recorded in 12th November 1999, before the Duzce earthquake with the magnitude 7.2, there had been many cases where the anomaly amplitude was not proportional to the magnitude of the earthquakes (Mb3 to Mb6).

The background noise of the measurement system is higher in the regions known with geothermal activity. Patterns looked for are different from this type of background activity but it still disturbs low amplitude data in selectivity. On the other hand correlation of the background noise to geothermal activity seems to be another research subject.

5. Conclusions

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 in future. All of the on line station data and the previously collected data can be reached through the internet site of the project http://deprem.itu.edu.tr This feature is thought to be giving transparency to the project so that open discussion will be allowed. Although an exact proportion could not be found yet between the sizes of anomaly patterns and magnitudes of correlating earthquakes, major earthquakes are aimed to be distinguished. Low depth of the major earthquakes in Turkey is an advantage for monopolar electric field measurement. Multilayer capacitor equivalent circuit model can be modified with some new parameters. A neural network based recognition and learning process is applied in the data acquisition center. This part of the project is studied in another related paper.

6. References

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