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Electric Charge Developed by Seismic Stress on Earthquake Sources and Its Effect on Animals*

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Abstract: In this paper we discuss about electric charge developed due to seismic stress at fault zone on earthquake. It has been shown that electric charge can vary according to geophysical circumstances i.e., developed charge may fluctuate for different geophysical states and its value may differ for surface and in the interior of the earth. The information will be useful for earthquake prediction, like some animals behave abnormally for a particular value of charge at particular distance from hypocenter/epicenter. A case study for Himalayas has been carried out for feasibility of using this precursor for the earthquake prediction.

Key words: Earthquake**,** Seismic stress, fault, electric field, animal's abnormal behavior

1. Introduction

Earthquake prediction is a pressing societal imperative due to their inflicted large damages and is one of the major scientific challenges. The solutions have been searched in past using earthquake precursors, in which one of the important aspect is the abnormal animal behavior. While lot of research work has been carried out for the geophysical precursors, animal behavior has not been explored to its full capacity for use in earthquake prediction[1]**.** The earthquake prediction can be done using the abnormal behavior of animals preceding earthquake occurrence in seismically active

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region because of their relatively more capability than humans of perceiving certain kind of geophysical stimuli which may precede earthquake[2, 3].

Precursors are defined as some anomalous changes prior to an earthquake occurrence[4]. One of the precursors before the earthquake occurrence is the change in the electromagnetic field which may be attributed to the anomalous animal behavior[5]. The electromagnetic field may be generated on the surface and inside the earth before earthquake due to seismic stress developed by piezoelectric effect at fault zone. This stress can also be developed due to other reasons[6]. Some animals can detect these changes in the electromagnetic field prior or during an earthquake occurrence and start behaving abnormally due to their sensitive organs to electromagnetic field.

Some animals show abnormal behavior in the range of electric field (700 to 200000) V/m. Rats, Mongolian gerbils, Djungarian hamsters, Guinea pigs, and Red Avadavat behave abnormally due to change in electric field intensity from (2 to 1000) V/m, (60 to 400) V/m, (30 to 800) V/m, (100 to 1600) V/m and (100 to 660) V/m respectively just before the earthquake[7]. Hence their abnormal behavior may lead to earthquake prediction. Such electric charge developed at fault zone may be calculated on the basis of the physics of the generation of fault and electro magnetic model of fault, which is presented in this paper.

2. Mathematical model

Seismic stress at fault zone

Generation of charge due to mechanical stress is called piezoelectricity which produces both positive and negative ions. The earthquake generation process can be described using the Reid's theory which states that the earthquakes are the result of sudden stress release on a fault[8]. This stress has been accumulating for long time period (millions of years) and when it exceeds the strength of the rock, energy is suddenly released in the form of earthquake. The already present stress in the earth (which is accumulated over a long time) is called initial stress and is represented as σ_0. When faulting takes place, new seismic stress patterns develops and the developed stress can be represented as σ_1. Then stress drop becomes, $\Delta\sigma = \sigma_0 - \sigma_1$[9]. This seismic stress σ_1, produce some electric charge due to piezoelectric effect in rock (for example, quartz, granite etc.). The stress induced electric polarization depends upon the property of earth or rock and piezoelectric coefficient 'α'. Piezoelectric coefficient can be determined experimentally in the laboratory for rocks of granite, quartz, olivine, and pyroxene etc.

An electromagnetic model of fault behavior based on dipolar charge generation is used to explain the pulsed field and the current, which cause abnormal animal behavior. Pulsed electric field is a wave packet of electromagnetic waves. The seismic stress drop $\Delta\sigma$ after the fault displacement can be given in a mathematical model of a fault such that

(2.1) $$\Delta\sigma = \mu (D/2a),$$

where, μ is the rigidity modulus of rocks, D is the displacement and 2a is the total subsurface rupture length of the fault[9]. Seismic stress parallel to fault plane is given as

(2.2) $$\sigma_0 = \mu (D'/2\beta),$$

where D' is initial velocity of the displacement and β is the shear wave velocity[7]. Now time dependent displacement, $D(t)$ is expressed using the fault displacement time τ. Fault displacement time is equal to displacement of fault divided by the initial velocity of displacement i.e.,

$$\tau = D/D' = (\Delta\sigma.2a.\mu)/(\mu.\sigma.2\beta).$$

The fault displacement (time dependent) is expressed as;[7]

(2.3) $$D(t) = D(1 - e^{-t/\tau}).$$

Hence, by the definition of strain, remaining strain is equal to change in length divided by total length i.e. $(D - D(t))/2a$ .Therefore, time dependent stress can be expressed as $\sigma(t) = \mu[D - D(t)]/2a$ .From equation (2.3), $\sigma(t) = \mu D e^{-t/\tau}/2a$ and then from equation (2.1), time dependent stress is equal to

(2.4) $$\sigma(t) = \Delta\sigma\, e^{-t/\tau}.$$

Charge developed due to seismic stress

The time dependent charge can be described as

(2.5) $$dq/dt = -\alpha(d\sigma/dt) - q/\in\rho,$$

where, q is the free charge caused by reduction of piezoelectric polarization at fault zone due to seismic stress release[7]. As the earth is conductive the charge developed due to seismic stress accumulated for hundreds of years becomes zero. But due to sudden release of seismic energy at the time of earthquake occurrence i.e., after faulting some charge is developed at fault zone. In starting, no electric field or electric charge is present at fault zone. But, when seismic stress is changed by faulting or local fracture of rocks, the electric charge *q (t)*, appear rapidly at fault zone.

To find out, *q (t)* equations (2.4) and (2.5) have been used[6]. The solution is given as follows:

$$d\,q\,/\,d\,t + \alpha.d(\Delta\sigma.e^{-t/\tau})\,/\,d\,t + q/\in\rho = 0,$$

$$d\,q\,/\,d\,t + \left\{\frac{\alpha\,\mu\,D}{2a}\right\} d\,(e^{-t/\tau})\,/\,d\,t + q/\in\rho = 0,$$

$$d\,q/\,d\,t + B'\left\{\frac{d\,(e^{-t/\tau})}{d\,t}\right\} + Aq = 0,$$

$$d\,q/\,d\,t - Be^{-t/\tau} + Aq = 0,$$

$$d\,q/\,d\,t + Aq = Be^{-t/\tau}, \tag{2.6}$$

where, $(A = 1/\epsilon\rho)$, $(B = \alpha\,\mu\,D\,/\,2a\,\tau)$ = Constant, ϵ is dielectric constant and ρ is resistivity of rocks. The equation (2.6) is a linear equation of first order of the form, $d\,y/d\,x + P(x)\,y = Q(x)$, where y is dependent variable and x is independent variable. To find out the value of charge *'q'* the equation is solved as follows:

Integrating factor for equation (2.6) is equal to $= e^{\int p\,dx} = e^{\int A\,dt} = e^{At}$, which implies

$$q.e^{A\,t} = \int (B.e^{-t/\tau}.e^{A\,t})\,dt + Constt.,$$

Hence, $q = e^{-At}\{\int (B.e^{-t/\tau}.e^{At})\,dt + Constt.\}$ is the general solution of equation (2.6).

On substituting the values of *A* and *B,* we get

$$q = e^{-t/\in\rho}\,[\int \{(\alpha\,\mu\,D\,/\,2\,a\,\tau).e^{-t/\tau}.e^{t/\in\rho}\}\,dt + Constt.],$$

$$q = e^{-t/\in\rho}\,\{(\alpha.\Delta\sigma)\,/\,\tau.\int (e^{-t/\tau}.e^{t/\in\rho})\,dt + C\},$$

$$q = e^{-t/\in\rho}\{(\alpha.\Delta\sigma)\,/\,\tau.\int e^{(t/\in\rho - t/\tau)}\,dt + C\},$$

$$q = e^{-t/\in\rho}\left[\{(\alpha.\Delta\sigma.\in\rho.\tau)\,/\,\tau\}.\left\{\frac{e^{t/\in\rho - t/\tau}}{\tau - \in\rho}\right\} + C\right],$$

$$q = e^{-t/\in\rho}\left[\alpha.\Delta\sigma\left\{\frac{\in\rho}{\tau - \in\rho}\right\}e^{t/\in\rho - t/\tau} + C\right].$$

Initially when time $t = 0$, electrical charge developed by polarization is cancelled by the electrical charge in conductive earth, therefore no electrical charge is present at fault zone. As time, t increases some charge, $q\ (t)$ remains in the earth, therefore on substituting, q = 0, when, t =0 in equation

$$0=\left[\alpha\,\Delta\sigma.\left(\frac{\in\rho}{\tau-\in\rho}\right)\right]+C\,,$$

$$C=-\alpha\,\Delta\,\sigma.\left\{\frac{\in\rho}{\tau-\in\rho}\right\}.$$

Hence, electric charge developed at fault zone, q is given by

$$q=\alpha\Delta\sigma\left\{\frac{\in\rho}{\tau-\in\rho}\right\}\left[e^{-t/\tau}-e^{-t/\in\rho}\right],$$

We know that fault displacement time $\tau=D/D'=(\Delta\rho/\sigma_0).(\alpha/\beta)$, which gives $\Delta\sigma=\tau.\sigma_0\,(\beta/\alpha)$ and therefore

$$q=\alpha.\tau\,\sigma_0\,(\beta/\alpha)\left\{\frac{\in\rho}{\tau-\in\rho}\right\}\left[e^{-t/\tau}-e^{-t/\in\rho}\right]. \tag{2.7}$$

This equation represents a pulsed charged density with a rise time of $\in\rho$ (or τ for $\in\rho>\tau$) and the decay time τ (or $\in\rho$). Charges are sustained in the fault zone so long as they are generated by the stress charges. Hence duration of time is the longer one of τ or $\epsilon\rho$. The electric field at fault zone is obtained using the relationship in equation (2.7), therefore electric field intensity

$$F(t)=q(t)\,/\,\varepsilon\,,$$

$$\therefore\ F(t)=\alpha\,\rho.\sigma_0\left\{\frac{\beta}{\alpha}\right\}\left[\frac{e^{-t/\tau}-e^{-t/\varepsilon\rho}}{1-\varepsilon\,\rho/\tau}\right],$$

The time dependent field intensity has sharp time of, $\epsilon\rho$ depending on the geology of the area and a slow decay time of τ which depends on the mode of fault movement or local fractures. Electromagnetic waves moves in all direction with the speed of light from fault plane of length, $2a$ and this developed electric charge, $q\ (t)$ polarize the whole body around the fault plane. Therefore, total polarization $p\ (t)$ of the charge, $\pm\ q\ (t)$ separated by $2a$ is given by $P=2a\,Q=2a\,A\,q$. We know that $M_0=\mu\,D\,A$ and $\Delta\sigma=\mu\,D\,/2a$, therefore $P=(M_0/\Delta\sigma)q$. On substituting the value of, q we get

$$P(t)=(M_0 / \Delta\sigma).q(t),$$

$$P(t)=(M_0 / \Delta\sigma).\alpha.\Delta\sigma\left\{\frac{\varepsilon\rho}{\tau-\varepsilon\rho}\right\}(e^{-t/\tau}-e^{-t/\varepsilon\rho}),$$

(2.8) $$P(t)=\alpha M_0\left\{\frac{\varepsilon\rho}{\tau-\varepsilon\rho}\right\}(e^{-t/\tau}-e^{-t/\varepsilon\rho}),$$

where earthquake moment, M_0 is given by moment magnitude, M_w such as $M_0=10^{1.5M+9.1}$, which gives $M_w=(1/1.5)\log M_0-(9.1/1.5)$; [10]

Hence, total charge at fault zone expressed as

$$Q(t)=\frac{p(t)}{2a},$$

(2.9) $$Q(t)=\alpha M_0 / 2a\left\{\frac{\varepsilon\rho}{\tau-\varepsilon\rho}\right\}(e^{-t/\tau}-e^{-t/\varepsilon\rho}),$$

where dielectric constant, ϵ and resistivity of earth, ρ correspond to the capacitance, C and impedance, R of rocks. During the earthquake, ($\tau >> \epsilon\rho$) and before the occurrence of the earthquake, ($\tau << \epsilon\rho$);[7]

3. Case study for Himalayas

An endeavor has been made to estimate the total charge at fault zone in case of probable earthquake occurrence in Himalayas. The past seismicity studies shows that the seismic sources in Himalayas are considered to generate earthquakes in the range[11, 12, 13] of 5 to 9. The subsurface rupture length for the various magnitudes has been calculated based on Wells and Coppersmith[12]**.** The total charge developed for magnitude 7 and 8 have been shown in Fig-1.a and b, respectively). The figures reveal the maximum total charge developed at the fault may be $1.39\text{x}10^{-15}$ and $0.86\ \text{x}10^{-14}$ coulomb for magnitude 7 and 8 respectively. The maximum charge has been observed to be developed at around 0.05 sec. The parameters assumed for the estimation of the electric charge and electric field intensity are given in Table-1.

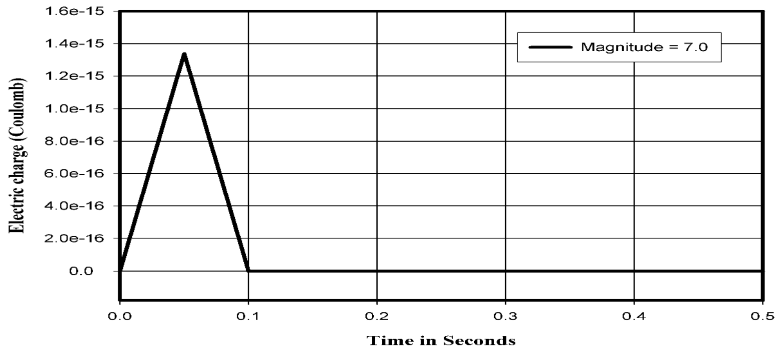

Fig.1(a). Total charge of fault zone for magnitude 7.0 at 41 km

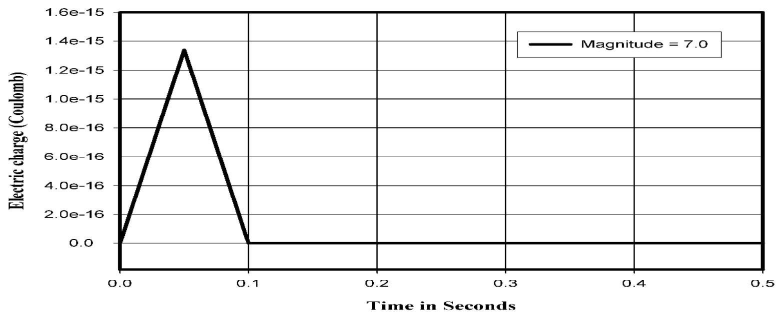

Fig.1(b). Total charge of fault zone for magnitude 8.0 at 200 km

4. Estimation of electromagnetic field at the surface

Seismic electric signal can be estimated analytically i.e., the ultra low frequency electromagnetic waves generated by developed charges give seismic electric signals. An equation of pulsed seismic electric signals have been derived[6]. This gives a wave packet of electromagnetic waves and might be used for early warnings.

Let θ, be the angle between the direction of the dipole and the distance R, from the hypocenter, then the electric field intensity $[\mu c N(x,t)]^{1/2}$ can be calculated on the basis of (Ikeya et al.)[6]**.** The time-dependent electric dipole moment generates the electromagnetic (EM) waves having a Poynting vector of

$$N(x,t) = (1/4\pi R)^2 (\mu_0 / c)\left[\frac{d^2 p}{d t^2}\right]^2 \sin^2\theta,$$

$$N(x,t) = (1/4\pi R)^2 (\mu_0 / c)\sin^2\theta \left[\alpha M_0 \left\{\frac{\in \rho}{\tau - \in \rho}\right\}\left\{e^{-t/\tau}/\tau^2 - e^{-t/\in\rho}/\in^2 \rho^2\right\}\right]^2. \tag{3.1}$$

Hence,

$$\mu.c.N(x,t) = \left(\frac{3\times 10^{-4}}{4\pi R^2}\right)\sin^2\theta \left[\alpha M_0 \left\{\frac{\in \rho}{\tau - \in \rho}\right\}\left\{e^{-t/\tau}\Big/\tau^2 - e^{-t/\in\rho}\Big/\in^2 \rho^2\right\}\right]^2,$$

where, c is the speed of light and R is the hypo central distance. Therefore the electric field intensity is represented by equation (3.2) and is reciprocally proportional to the distance *R*.

$$[\mu.c.N(x,t)]^{1/2} = (0.00177)\left(\frac{\sin\theta}{R.}\right)\left[\alpha M_0 \left\{\frac{\in \rho}{\tau - \in \rho}\right\}.\left\{e^{-t/\tau}/\tau^2 - e^{-t/\in\rho}/\in^2 \rho^2\right\}\right] V/m. \tag{3.2}$$

The electric field intensity has been estimated using equation (3.2) for the case of Himalayas which reveals that the electric field intensity ranges from (0.133457 to 0.0) V/m, (4.3 to 0.0) V/m, (135 to 0.0) V/m, (4250 to 0.0) V/m and (134000 to 0.0) V/m for magnitude 5.0, 6.0, 7.0, 8.0, 9.0, respectively. The maximum electric field intensity has been observed around 0.035 sec. of faulting, at 90^0 from dipole direction and at 1 km from the hypocenter of earthquake. Similarly we can estimate variation in electric field intensity at different distances from hypocenter and at different angles from dipole direction. The electric field intensity around the fault has also been estimated for the magnitudes 7 and 8. The Fig- 2.a and b, show the electric field intensity around the fault for, R =1 km and θ = 90°, using equation (3.2).

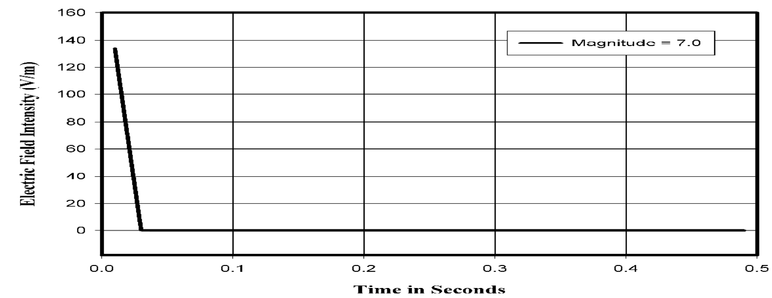

Fig.2(a). Electric field intensity around fault zone at 90 degree at a distance of 1 km for magnitude 7.0

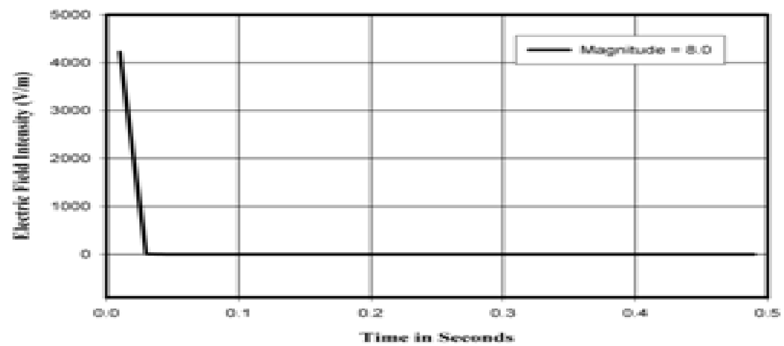

Fig. 2(b). Electric field intensity around fault zone at 90 degree at a distance of 1 km for magnitude 8.0

5. Results and Discussion

An endeavor has been made in the present study to estimate the electric field intensity due to generation of earthquakes which may be used as an earthquake precursor. Some animals show abnormal behavior at a particular distance from hypocenter and at particular angle from dipole direction for fix magnitude due to their electro sensitive organs. The paper has shown encouraging results of using abnormal animal behavior before an earthquake for prediction in many countries and it requires its due attention in Indian context, which may use for earthquake prediction.

Table -1

Fault displacement time before earthquake 'τ'	Rigidity of rocks-(for crystals) 'μ'	Time constant '$\epsilon\rho$'	Piezoelectric coefficient for granite 'α'	Resistivity of earth for granite 'ρ'	Time 't'	Vacuum permeability 'μ_0'
3×10^{-3} sec	3×10^{11} dyne/cm^2	7×10^{-5} sec	10^{-14} C/N	$10^{8}\ \Omega$ m	10 sec	$4\pi \times 10^{-7}$ N/A^2

References

1. T. Rikitake, Earthquake Prediction, *Amsterdam, the Netherlands: Elsevier Scientific Publishing Company*, (1976).
2. Z. Guozhang, Some characteristics of animal behavior prior to earthquakes. In: Earthquake prediction, *Terra scientific Publishing Company (TERRAAPUB)*, Tokyo Unesco, Paris, (1984) 246.
3. A. A. Nikonov, Abnormal Animal Behaviour as a Precursor of the 7 December 1988 Spitak, Armenia, Earthquake, *In Natural Hazards*, **6** (1992)1-10.
4. H. Sato, Some precursors prior to recent great earthquakes along the Nankai trough, *J. Phys. Earth, 25, Suppll*, (1977) 115-21.
5. C. Y. Tang, Bases for the prediction of the Lungling earthquake and the temporal and special characteristics of precursors, *Proceedings of the Chinese Earthquake Prediction by the 1977 Delegation of the Seismological Society of Japan. Tokyo, Seismological Society Japan*, (1978) 13-32.
6. M. Ikeya, H. Matsumoto and Q. H. Huang, Alignment silkworms as seismic animal anomalous behavior (SAAB) and electromagnetic model of a fault: a theory and laboratory experiment, *ACTASEISMOLOGICA SINICA*, **11(3)** (1998) 365-374.
7. M. Ikeya, H. Furuta, N. Kajiwara and H. Anzai, Ground Electric Field Effects on Rats and Sparrows: Seismic Anomalous Animal Behaviors (SAABs), *Jap. J. Appl. Phys*, **35(1)(8)** (1996) 4587-4594.
8. H. F. Reid, The Elastic Rebound Theory of Earthquakes, *Bulletin of Department of Geology, U.S.A.*, **6** (1911) 413-444.
9. H. Kanamori and D. L. Anderson, Theoretical basis of some empirical relations in seismology, *Bulletin of the Seismological Society of America*, **65(5)** (1975) 1073-1095.
10. T. C. Hanks and H. Kanamori, A Moment Magnitude Scale, *Journal of Geophysical Research*, **84(B5)** (1979) 2348-2350.
11. M. L. Sharma and M. Arora, Prediction of seismicity cycles in Himalayas using ANN, *Acta Geophysica Polonica*, **53(3)**(2005) 299-309.
12. M. L. Sharma and R. Dimri, Seismic hazard estimation and zonation of northern Indian region for bed rock ground motion, *Journal of Seismology and Earthquake Engineering*, **5(2)** (2003) 23-34.
13. D. Shanker and M. L. Sharma, Estimation of seismic hazard parameters for the Himalayas and its vicinity from complete data files, *Journal of Pure and Applied Geophysics (PAGEOPH)*, **152(2)** (1998) 267-279.
14. D. L. Wells and K. J. Coppersmith, New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement, *Bulletin of the Seismological Society of America*, **84(4)** (1994) 974-1002.