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CHIRAL RATIO OF THE COMPRESSIONAL AND SHEAR VELOCITY FOR THE DETERMINATION OF STRONG EARTHQUAKE MAGNITUDES THROUGH HIGH-FREQUENCY ENERGY RADIATION

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ABSTRACT

In this short paper, we define and determine the connection between an electromagnetic chiral theory and the Hara's relation (high-frequency energy radiation from the arrival time of a P-wave) under a chiral approach. We consider the possibility that gravity breaks parity, with left and right handed gravitons coupling to matter with a different Newton's constant and show that this would affect the earth dynamics and induce strong earthquakes. This theory allows to determine chiral changes on ratio of the compressional velocity to the shear velocity for the estimation of earthquake magnitudes. Through measurements of high-frequency energy radiation, it is possible to determine the amplitude of strong earthquakes as occurred in Chile and Japan recently. On April 25, 2015, Saturday a strong of local magnitude 7.8 on the Richter scale earthquake hit west side of Nepal in the area Barpak, Gorkha district between capital Kathmandu and tourist town Pokhara. This earthquake was followed by many powerful aftershocks and an unexpected aftershock of local magnitude 6.8 on the Richter scale hit east side of Nepal in the area Dolkha on Tuesday May 12. The earthquakes caused extensive damage to buildings and thousands of deaths and injuries and were even felt in Pakistan, India and Bangladesh. No radiation data is obtained from Nepal earthquake 2015. Our proposed theory also can be applied for this case.

Keywords: Chiral waves, gravity, earthquake, P waves, radiation, rotation

INTRODUCTION

Earthquakes occur primarily along plate boundaries; the frequency and type of events vary with the type of boundary. Plates interact with one another in one of the three ways: they diverge, converge or slide past one another. Scientists have known for decades that the ongoing movements and collisions of the plates, a so-called push/pull mechanism, are responsible for sculpting continental features around the planet, usually where plates are either moving apart or coming together.

Gravity and mantle convection are two driving forces for the movement of plates.

Phenomenologically, between plates we have the Newton's law, $\vec{F}_N - \vec{F}_f = m\vec{a}$ where $\vec{F}_N$ is the Newton's gravitational force proportional to G_N, $\vec{F}_f$ is the friction force between plates. When the derive velocity is constant, $\vec{a} = 0$ so $\vec{F}_N - \vec{F}_f = 0$. However, if G_N changes for short time instants, we can have a trigger to produce a earthquake. In this paper, in connection with gravity, we consider the possibility that gravity breaks parity, with left and right handed gravitons coupling to matter with a different Newton's constant and show that this would affect the earth dynamics and induce strong earthquakes. Also, should there be a cosmic background of gravity waves, the effect would translate into anomalous CMB polarization [1, 2].

Following [1], we can parametrize the chiral asymmetry by:

$$G^{R/L} = G_N(1 \mp \frac{1}{\gamma})^{-1} \tag{1}$$

where G_N is the Newton's gravitational constant, R(L) means Right (Left) polarized gravitons, γ is the Immirzi parameter which is related to the chiral electromagnetic parameter T_0 by $1/\gamma = k_0 T_0$, where $k_0 = \omega/c$ is the wave number of the electromagnetic radiation; a large γ means no measurable chirality. The sign of γ matters and $\gamma > 0$ means stronger gravity for R gravitons and if $|\gamma| < 1$ then gravity becomes repulsive for one of the R or L modes. This effect can produce strong anomalous forces in earthquake phenomena due to the factor $1 \mp \frac{1}{\gamma}$ if strong bursts of chiral gravitational waves reach the Earth.

General relativity is parity symmetric, so it is pertinent to ask how radical the modifications of its principles need be to allow parity asymmetry in the form of $G^L \neq G^R$. Chiral gravitation has been associated with a Chern- Simons term [3, 4] coupled to a dilaton, or the presence of spinors. But none of these mechanisms induce parity breaking at leading order in the graviton propagator, as implied by $G^L \neq G^R$. But the possibility of such a leading order effect can be motivated from several considerations including Euclidean gravity and the fact that CP violating instanton effects are expected to arise in a path integral quantization of chiral actions such as the Plebañski's action [5].

There is a lot of observational evidence concerning rotational motions on the Earth's surface excited by earthquakes, we can infer the existence of rotational motions in earthquake focal zones. It is observed that rotational motions (twist) in earthquake sources naturally excite rotational seismic waves, solitons and chiral waves [6, 7, 8].

The key idea of this article consists in to verify the description of rotational seismic waves into a chiral regime [13, 14] by considering chiral rotational seismic waves excited in earthquake sources in strong earthquakes which produce tsunami events. We can distinguish two kinds of rotational seismic waves: (1) rotational longitudinal waves, that is, PR waves; and (2) rotational shear waves, that is, SR waves. Rotational seismic waves propagate faster in solid rocks and much slower in fractured media along tectonic faults. It has been observed that these waves may have a form of rotational seismic solitons and that they can trigger earthquakes [9]. Because of

the fact that solitons can propagate without any loss of energy, these waves are extremely important carriers of seismic energy.

The existence of rotational motions excited by earthquakes [10] and measurements of seismic spin and twist waves were obtained also by other authors [6-8]. Most earthquakes occur under a certain high level of confined pressure. The constitutive law during an earthquake is controlled by a macroscopic property of the fault such as macroscopic roughness of the fault, thickness of the fault gauge layer, geometry of the fault, the macroscopic change of the fault strength, and so on.

BASIC THEORY OF CHIRAL ELECTROMAGNETIC AND S SEISMIC WAVES

The evidence of chirality behavior suggests that if it is included in the conditions to obtain a metamaterial behavior of a medium further progress will be obtained. In this short paper, we propose to investigate the conditions to obtain a metamaterials having simultaneously negative permittivity ε and negative permeability μ and very low eddy current loss.

As a initial point, we considerer a media where the electric polarization depends not only on the electric field $\mathbf{E}$, and the magnetization depends not only on the magnetic field $\mathbf{H}$, and we may have, for example, constitutive relations given by the Born-Federov formalism [14]:

$$\mathbf{D}(\vec{r},\omega) = \varepsilon(\omega)(\mathbf{E}(\vec{r},\omega) + T_0(\omega)\nabla \times \mathbf{E}(\vec{r},\omega)) \qquad (2)$$

$$\mathbf{B}(\vec{r},\omega) = \mu(\omega)(\mathbf{H}(\vec{r},\omega) + T_0(\omega)\nabla \times \mathbf{H}(\vec{r},\omega)) \qquad (3)$$

The pseudoscalar T_0 represents the chirality of the material and it has length units. In the limit $T_0 \to 0$, the constitutive relations (2) and (3) for a standard linear isotropic lossless dielectric with permittivity ε and permeability μ are recovered.

According to Maxwell's equations, electromagnetic waves propagating in a homogeneous dielectric magnetic material are either positive or negative transverse circularly polarized waves, and can be expressed as:

$$\mathbf{E}^{\pm}(\vec{r},t) = \hat{E}_0^{(\pm)} e^{-j(k_{\pm}z - \omega_0 t)} \qquad (4)$$

$$\mathbf{H}^{\pm}(\vec{r},t) = \hat{H}_0^{(\pm)} e^{-j(k_{\pm}z - \omega_0 t)} \qquad (5)$$

where $E_0^{\pm} = E_0(\hat{x} \pm i\hat{y})$ and $\nabla \times \vec{E}^{\pm}(\vec{r},t) = \mp k_{\pm}\vec{E}^{\pm}$, $k_{\pm} \geq 0$ is the chiral wave number.

If the phase velocity and energy flow are in the same directions, and from Maxwell's equation, one can see that the electric field $\mathbf{E}$ and magnetic field $\mathbf{H}$ and the wave vector $\vec{k}$ will form a right-handed triplet of vectors. This is the usual case for right-handed materials. In contrast, if the phase velocity and energy flow are in opposite directions, and $\mathbf{E}$, $\mathbf{H}$, and $\vec{k}$ will form a left-handed triplet of vectors. This is just the peculiar case for left handed materials where the effective permittivity ε and the effective permeability μ are simultaneously negative. So, for incident waves of a given frequency ω, we can determine whether wave propagation in the composite is right handed or left handed through the relative sign changes of k.

In terms of chiral magnetic potential $\mathbf{A}_c$, from the Maxwell's equations, we have the wave equation:

$$\nabla^2 \mathbf{A}_c + \frac{k_0^2}{1-k_0^2 T_0^2}\mathbf{A}_c + 2\frac{\omega^2 \mu\varepsilon T_0}{1-k_o^2 T_0^2}(\nabla \times \mathbf{A}_c) = 0 \qquad (6)$$

As $k = \sqrt{k_x^2 + k_y^2 + k_z^2}$, if $k_x = k\sin\theta$, $k_y = 0$, and $k_z = k\cos\theta$, we have the matrix:

$$(7)$$

$$\begin{pmatrix} -k^2(1-k_0^2 T_0^2)+k_0^2 & -2jk_0^2 kT_0\cos\theta & 0 \\ 2jk_0^2 kT_0\cos\theta & -k^2(1-k_0^2 T_0^2)+k_0^2 & -2jk_0^2 kT_0\sin\theta \\ 0 & 2jk_0^2 kT_0\sin\theta & -k^2(1-k_0^2 T_0^2)+k_0^2 \end{pmatrix}\begin{pmatrix} A_x \\ A_y \\ A_z \end{pmatrix} = 0$$

The dispersion relation of the transversal wave is:

$$(-k^2(1-k_0^2 T_0^2)+k_0^2)^2 - 4k_0^4 k^2 T_0^2 \, (\sin^2\theta + \cos^2\theta) = 0 \Rightarrow k = k_\pm = \pm k_0/(1\pm k_0 T_0),$$

that is

$$k_\pm = \pm k_0/(1\pm k_0 T_0) = \pm\frac{\omega}{c}(1\pm k_0 T_0)^{-1} \qquad (8)$$

These results are derived from the Chiral Electrodynamics with T_0 as the chiral parameter and $k_0 = \omega/c$ [13, 14, 15]. In connection with seismic events, the Elastodynamics is linked with Electrodynamics through the transverse waves.

Seismic waves encountering interfaces that separate rocks of different elastic properties also undergo reflection, refraction, and scattering phenomena and chiral materials are noncentrosymmetric due to handedness in their microstructures. The elastic field behavior in a chiral medium is readily described herein using the governing equations and constitutive relations for noncentrosymmetric, isotropic micropolar materials. Accordingly, linearly polarized longitudinal waves and left and right circularly polarized transverse waves are eigenstates for elastic waves in the chiral medium.

There are two classes of seismic body waves which travel through the interior of the Earth: P waves and S waves. P waves are the fastest seismic waves, and consequently, the first to arrive at any given location. Torsion waves, often called S waves, represent the spiraling motion of particles twisting between inner structures. P waves are usually the first to be recorded on a seismogram because they travel the fastest. S waves usually have more height, or amplitude, than P waves. The ratio of the compressional velocity to the shear velocity v_P/v_S is important prior to an earthquake. Here we show that this ratio is a function of the chiral parameter. The amplitude of the waves can help to reveal information about the magnitude of an earthquake and the circular polarization of S waves can reveal the origin of earthquake. S waves as well as electromagnetic waves are transverse in nature, so that the high frequency energy radiation detected during an earthquake (Figures 1 and 2) must be governed by similar equations (eq. 8),

so for the S waves we have $k_{S\pm} = \pm\dfrac{\omega}{v_S}(1 \pm k_s T_s)^{-1}$ with $v_S = \sqrt{\mu/\rho}(1 \pm k_s T_s)$ where $v_s = \sqrt{\mu/\rho}$ is the S wave velocity, μ is the Lamé parameter and ρ is the density factor. The novel result here is that in our chiral theory in the interior of the earth we make $c \to v_s$. The P waves also are modified by chiral effects due to the Lamé parameter $\mu \to \mu(1 \pm k_s T_S)^2$ so $v_P = \sqrt{(\lambda + 2\mu)/\rho}$.

High resolution imaging with microseismic events requires the use of large and consistent data sets of seismic phase arrival times. In particular the S phase is important to derive physical parameters of the subsurface. Typically this phase is identified on one of the horizontal seismogram components by a change of signal amplitude and frequency as compared to the previous P phase. However, reliable S phase identification can be difficult for local events because of a signal overlap with the P coda, the presence of converted phases, and possible S wave splitting due to anisotropy due to the breaking of rock crystals. The seismic velocity anisotropy may be considered as a chiral effect.

The change in the velocity of the longitudinal P-wave is found by measuring the change in the ratio of the P-wave velocity to the S-wave velocity v_p/v_s. The v_p/v_s ratio is obtained from an analysis of the travel times of P- and S- waves [8]. Denoting the arrival times of P- and S-waves by t_p and t_s respectively, the S - P time versus t_p relation can be expressed by a straight line on the $(t_p - t_s), t_p$ plane. The inclination (m) of the line is given as: $m = -(t_p - t_s)/t_p = \Delta t/t_p$. Here, m is related with the normalized chiral wave number $k_c/k_S = 1/1 \mp k_S T_S$. We make the connection $k_o T_0 = \gamma^{-1}$ of the high-frequency energy radiation and the gravitational factor γ^{-1} from the arrival time of a P-wave. If the propagation path for both waves is assumed to be identical, we obtain: $v_p t_p = v_s t_s$ so that we have: $m = v_p/v_s - 1$. Therefore, it is seen that the v_p/v_s ratio is deduced from m calculated on the basis of travel-time analysis and the factor $v_P(v_p/v_s - 1)^{-1} \approx 7-8\,\text{km/s}$ without the chiral parameter T_S and it is used to study earthquakes [16]. Here, the S wave velocity is modified by the chiral factor $k_s T_s$, $v_S = \sqrt{\mu/\rho}(1 - k_S T_S)$. This approach may be treated from a theoretical point of view and gives an excellent argument to propose a prediction system to prevent the occurrence of great cataclysms. It may be useful in linearized earthquake location, confidence regions on the hypocenter, epicenter and focal depth which can be computed under certain assumptions and using different types of statistics [17, 18].

DETERMINATION OF EARTHQUAKE MAGNITUDES
When considering the problem of electromagnetic emissions correlated with earthquakes, one is often faced with an overwhelming problem of complexity, because the mechanism of wave generation is not entirely understood. Several observations of Very Low Frequency (VLF) emissions apparently associated with earthquakes, are recorded independently at ground-based stations and on satellites. Recently, Hara [11-12], developed a new method to determine earthquake magnitudes using the following formula: $M = \alpha \log A + \beta \log L + \gamma \log \Delta t + \delta$, where M is an earthquake magnitude, A is the maximum displacement during high-frequency energy radiation from the arrival time of a P-wave, L is the epicentral distance, Δt is duration of high-frequency energy radiation. The duration of high-frequency energy radiation can be estimated by

band-pass filtering of first arriving P-waves, $\alpha, \beta, \gamma, \delta$ are 0.79, 0.83, 0.69, and 6.47, respectively (the units of $A, L, \Delta t$ are m, km, and s, respectively). Here we suppose that our high-frequency energy radiation from the arrival time of a S-wave corresponds to our chiral wave with $k_c = k_s$ [13, 14, 15]; when an S- or P-wave strikes an interface at an angle other than 90 degrees, a phenomenon known as mode conversion occurs. If the interface is between a solid and liquid, S becomes P or vice versa. However, even if the interface is between two solid media, mode conversion results, so the modified M is given by

$$M \approx \alpha \log A + \beta \log L + \gamma \log \Delta t (1 + k_s T_s) + \delta, \qquad (9)$$

with $k_s T_s = 0.1$.

To the strong earthquake we applied this method to the February 27, 2010, Chile Earthquake (the origin time: 06:34:14 UTC; the location 35.846°S, 72.719°W after USGS). Data of measurements of high-frequency energy radiation show that the estimated duration is 138.6 sec. The estimated magnitude using the above formula is 8.70. Although this estimate is smaller than 8.8 from the Global CMT and USGS W Phase MT, it is consistent with them considering its uncertainly (around 0.1 in magnitude unit) [11-12].

Figure 1 shows a set of measurements of high-frequency energy radiation. The upper, middle and lower traces are an observed seismogram, the squares of the band-pass (2-4 Hz) filtered seismogram, and its smoothed time series (normalized by the maximum value), respectively. "A" and "F" in the lower trace denote the arrival of P-wave and estimated end of high frequency energy radiation, respectively. For strong earthquake "A" also can denote the arrival of S-wave due to the occurrence of mode conversion. Also we can apply this method to the 2011 off the Japan Pacific coast of Tohoku Earthquake on March 11 (the origin time: 05:46:23 UTC; the location 38.322°N, 142.369°E after USGS). In Figure 2 we show a set of measurements of high-frequency energy radiation. The estimated duration is 170 sec. The estimated magnitude using the above formula is 9.04, which well agrees with M_w 9.0 from JMA, 9.0 from the USGS W Phase moment solution, and 9.1 from the Global CMT solution.
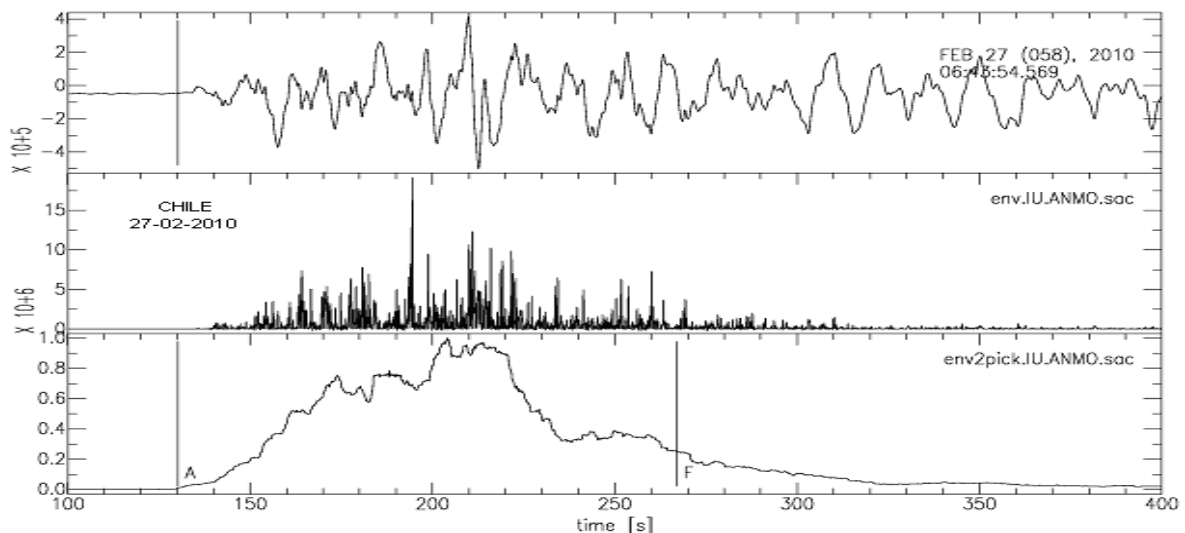
Figure 1. A measurement of high frequency energy radiation of the February 27, 2010 Chile Earthquake. This radiation is strongly linked to S-waves.
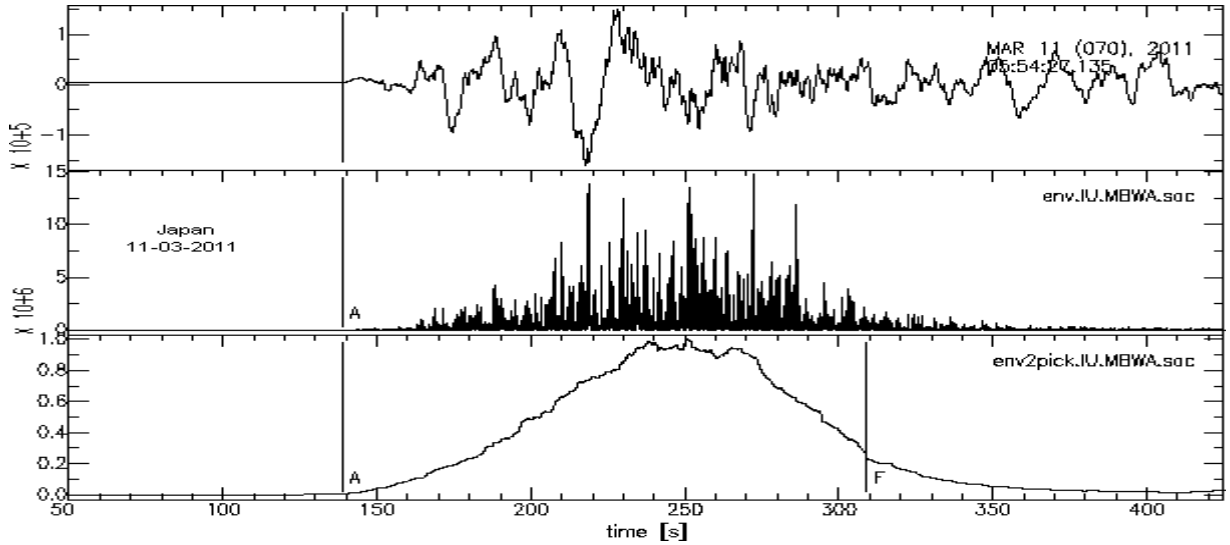

Figure.2 A measurement of high frequency energy radiation of Pacific coast of Tohoku Earthquake on March 11, 2011.

The Nepal Earthquake with M_w 7.9 on the Richter scale has taken place in a contact zone of the Eurasian and Indian plates where tectonic stresses accumulate. Therefore, there is a singular event [19-20]: This is a subduction zone where there is a convergence between plates, with an average speed of about 4.5 cm per year. Similar fact occurs in Chile with de Sudamerican plate and the Nazca plate. So this approach can be applied to Nepal. However, in this country it is important to develop a seismological system to make measurement of high frequency energy radiation.

METHOD OF PREDICTING EARTHQUAKES

As our main goal is to define the connection between the Rikitake's theory (seismic P-waves), and the Hara's relation (high-frequency energy radiation from the arrival time of a P-wave). We find this connection through the dilatation factor $\Delta t' = \Delta t / \xi(x)$ which is incorporated to eq. (9). The meaning of time may be considered in two ways: (a) the time based on the reading of clocks which suffer dilatation due to chiral fields [13-14], and (b) the time as it is accepted as in special relativity. In order to obtain reproduction of the fixed unit of time relating to the world which would nor suffer dilatation (chiral factor T=0), we can introduce a time space function $\xi(x)$ which transforms an interval of proper time Δt in our information on time according to $\Delta t' = \Delta t / \xi(x)$ where we have $\xi(x) = 1 + \overline{\chi}$, $\overline{\chi} = \chi + \delta\chi(x)$ and $\delta\chi(x)$ take into account the occurrence of earthquake phenomena. Here, we propose two hypotheses: a) the chiral potential (T parameter) of a chiral theory [13-14], is unambiguously related to the cosmological dilatation function $\xi(x)$ (see appendix) and the radiation eigenwaves are circular polarized waves with the same polarization of rotational seismic waves; (b) the difference in time Δt in the chiral Weyl's theory is the same as the time variable of time involved in the Hara's formula, ($M = \alpha \log A_{eq} + \beta \log L + \gamma \log \Delta t + \delta$), and the empirical relationship of Rikitake ($\ln \Delta t = 0.75M - 4.27$).

Then, if the process leading to the occurrence of the earthquake influences changes of our information on time, then possibility of its prediction can be suggested. If we consider a large plate of Earth's crust, for example in Chile from Antofagasta, point P_1 and Arica, point P_2, the dilatation function ξ obtained from the chiral Einstein's theory gives a difference of the cosmological forces between P_1 and P_2. If ξ or $\delta\chi(x)$ is properly correlated with the A_{eq} factor obtained from the solution of the P-waves equation and M, then we are in a position to propose an original prediction system as a early detection system for earthquakes.

Considering two atomic clocks C_1 and C_2 at points P_1 and P_2. C_1 and C_2 starting at the same time and at any subsequent instant, as their distances of the Earth's center are approximately equal, they give the same information on time $T_1' = T_2'$. However, if at point P_1 the adhesion between adjacent plates is smaller than at point P_2 then the difference in forces due to the relative dilatation $\xi(x)$, give a time difference of atomic clocks, that is if $\Delta T_{12}' = T_1' - T_2' \neq 0$ appears, then an earthquake can be expected either in the neighbourhood of P_1 or P_2. This uncertainty can be removed with the aid of a third clock C_3 at any point P_3. In general, if a certain region could be covered by n clocks at any C_i we should form $\sum_k \Delta T_{ik}'$ for C_i where $\sum_k \Delta T_{ik}' \to \max$ we should have a point at which an earthquake can be expected. Our proposed work is to find the correct relationship between $\delta\chi(x)$ or $\bar\chi(x)$ and A_{eq}, is the maximum displacement during high-frequency energy radiation from the arrival time of a P-wave.

CONCLUSIONS
In this short paper, we defined and determined the connection between the chiral's theory (seismic P-S-waves), and the Hara's relation (high-frequency energy radiation from the arrival time of a P-wave) under a chiral approach. This approach is related to chiral electromagnetic parameter, the gravitational Immirzi's factor which is important in gravitational chirality and S-wave with circular polarization. This connection is a support for the relation $v_P(v_p/v_s(1-k_S T_S)-1)^{-1}$, which gives information of the maximum displacement of an earthquake during high-frequency energy radiation arising from the arrival time of a P-wave or S-wave at a specific location. This approach may be treated from a theoretical point of view and gives an excellent argument to propose a prediction system to prevent the occurrence of great cataclysms. It may be useful in linearized earthquake location, confidence regions on the hypocenter, epicenter and focal depth which can be computed under certain assumptions and using different types of statistics. This model is a support to propose an early detection system which can give information of the maximum displacement of an earthquake during high-frequency energy radiation arising from the arrival time of a P-wave or S-waves at a specific location.

The **2015 Nepal earthquake** (also known as the **Gorkha earthquake**), which killed more than 8,500 people and injured more than twice as many, occurred at 11:56 NST on 25 April, with a <u>moment magnitude</u> (M_w) of 7.9 <u>M_w</u> or 8.1 <u>M_s</u> and a maximum <u>Mercalli Intensity</u> of IX (*Violent*), is an appropriate example to apply this theory and measurements. However, in this country it is important to develop a modern seismological system to make measurement of high frequency energy radiation producing before and after strong earthquakes.

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