ISSN 0974 - 9373

Vol. 15 No.4 (2011) Journal of International Academy of Physical Sciences pp. 435-445

Unusual Animal Behavior Due to Acoustic Waves Generated by an Earthquake

Neeti Bhargava and P. Pradhan
Department of Mathematics, Gurukula Kangri University, Haridwar
Email: neetibhrgv@gmail.com

V. K. Katiyar
Department of Mathematics, Indian Institute of Technology, Roorkee

M. L. Sharma
Department of Earthquake and Engineering, Indian Institute of Technology, Roorkee

(Received December 22, 2010)

Abstract: The socio-economic disastrous affect of moderate to strong earthquakes on the society has made it imperative to search for the methods to predict occurrence of earthquakes. Many of the observations in the past in highly seismic active regions have reported abnormal behavior of animals before the occurrence of earthquakes. The abnormal behavior can be attributed to various aspects including the sounds generated before and during occurrence of earthquakes. Seismic waves prior to occurrence of earthquakes have been found to contain a large spectrum of frequency content including very low frequency components also. Animals, aware of super-and sub-sonic frequencies, may hear the initial sound waves of an earthquake, which are otherwise inaudible to humans. Some animals living within seismically active region have been found to be affected by these very low frequency signals (LFS) because of their organs sensitive to low frequency vibrations. Due to some anatomical and neurological changes into their inner ear some aquatic animals can hear infrasonic sound of earthquake. For the purpose, a simple mathematical model has been developed to study the dynamics of the inner ear of animals. The model describes the cochlear mechanics by a set of differential equations relating pressure and displacements in the inner ear. This provides a base for investigating the effects of frequency of seismic waves, on pressure difference along basilar membrane. Hence dynamics of the cochlea would be describing the sensitivity of animal ear in a particular range of frequency of sound waves, which may be useful for prediction of earthquake.

Keywords: Earthquake, animal models, seismic waves, unusual animal behavior, prediction

1. Introduction

It has been observed that earthquakes are generally, but not necessarily, preceded by some signals mainly divided into geophysical precursors and others which also contains the unusual animal behavior. The earthquake prediction can be done using the abnormal behavior of animals preceding earthquake occurrence in seismically active region because of their relatively more capability than humans of perceiving certain kind of geophysical stimuli[1-4] Animals have been known to perceive the infrasonic waves carried through the earth by natural disasters and can use this wave as an early warning. Animals were reported to flee the area long before the actual tsunami hit the shores of Asia.[5] Some geophysical precursors tested on animals and it has been found that some species of animals pick up very low frequency sound waves below 50 Hz. i.e. infrasound of seismic waves that human cannot pick up. For example, birds (pigeons, owls) are much more sensitive than humans, rock doves and some other species of birds reportedly can detect frequencies of foreshocks typically in the range of (0.1 to 10) Hz; fish even more so, since water transmits these sounds more efficiently than air. There have been some reports of abnormal behavior with large animals, cats, dogs, rabbits, rats, mice, mussels, pigs, hippo's are able to detect the sound far out the range of human ear, can pick up infrasonic sound waves at great distance[6], In Japan, unusual behavior of catfish before the 1855 Edo earthquake was reported. Many fish jumping in a pond just one day before the great Kanto earthquake occurred was reported[7, 8].

According to (Emily Shepard, 2003)[9], blue whales on the other side of the ocean can hear infrasound calls and other whales also use infrasound to communicate. A case study involving pigeons show that, these small birds can detect infrasound. Some animals may actually able to feel the rumblings of the earth deep beneath us for example elephants can detect suitable seismic vibration from the ground from great distances. Elephants and whales have the most similarities for uses of infrasonic waves,[10]. The lowest frequency of an elephant rumble is 14 to 40 hertz. The other is that elephants use the air and ground as mediums for their infrasound where as whales obviously use water, but larger animals are generally reported as being less able to predict earthquakes.

To recognize the reason behind the abnormal behavior of animal due to low frequency signals, a mathematical model is presented in this paper. The cochlear mechanics of animal's inner ear has been described with the help of following model.

2. Mathematical Model for Dynamics of Cochlea of Animal

According to (Wikibooks[11]), Fig. 1, shows the anatomy of animal's inner ear. Animals inner ear has three essential components outer ear, middle, and inner ear, as same as in human ear, but there is some difference between the size and shape of their organs due to which that particular animal can hear infrasound which is inaudible to humans, for example shape of three tiny bones; malleus, incus, stapes (in the middle ear) is differ, semicircular canal is differ and also length and width of basilar membrane is also smaller that human basilar membrane and varies according to animals.

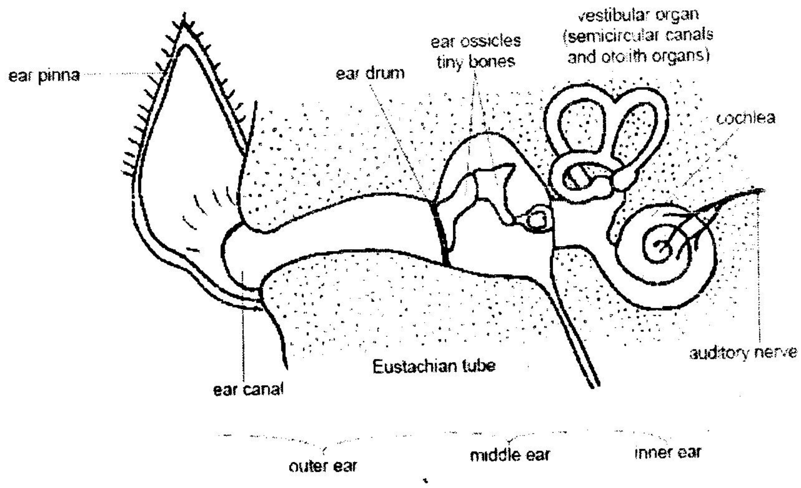

Fig. 1- Anatomy of animal ear, [After –Ref.[11]]

Modeling of animal inner ear will be used for calculating effect of seismic waves of various frequency ranges, by co-relating the neural network of animal cochlea and mathematical equations, and with the help of a mathematical model forecasting of earthquake might be possible and for differ geophysical condition the effect of seismic wave on animals may be differ. Further, mathematical model will be developed to study the dynamics of the inner ear of animal. The model should be able to describe the cochlear mechanics by a set of differential equations relating pressure and displacements in the inner ear which will provide a base for investigating the effect of frequency on pressure difference along basilar membrane. Hence dynamics of the cochlea would be describing the sensitivity of animal in a particular range of frequency of sound waves.

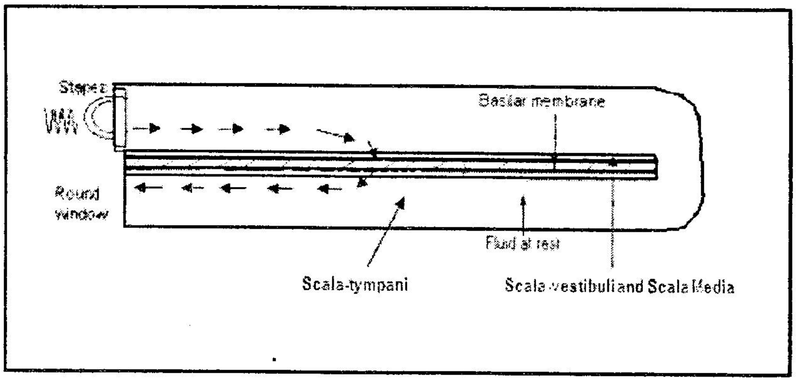

Fig.2 Geometrical model of the cochlea of animal

A mathematical model is proposed in an attempt to elucidate the various factors influencing the cochlear dynamics. The objective of our study is to find the expressions for pressure difference in the two chambers (i.e. scala vestibula and scala tympani), at different distances from the stapes and for different frequencies of seismic waves. To study the dynamical properties of cochlea, the geometry of the cochlea is considered, as shown in *fig-2.* The middle ear converts the acoustic pressure into a force, which is amplified by the middle ear ossicles (i.e. three tiny bones mallus, incus, and stapes). The ossicles are attached to the oval window, i.e. membrane is part of the inner ear and a snail shaped organ is called cochlea as shown in *fig-1.* Cross-sectional area of the cochlear canal, the density of the fluid filled in it and the mechanical properties of the partition i.e. basilar membrane are important factors in the dynamic behavior of cochlear canal

Pressure difference across the basilar membrane can be written as; [12]

(2.1) $$p = p_v - p_t .$$

It must be balanced by forces resulting from the displacement of the cochlear partition. There are three kind of forces acting; inertial force, frictional force and elastic force. These forces are proportional to acceleration, velocity, and the displacement of the partition respectively, so that equilibrium forces can be expressed by [12];

(2.2) $$pb = mv' + rv + k\int_0^t v\,dt,$$

(2.3) $$p\,b = M\frac{d^2S}{dt^2} + F\frac{dS}{dt} + ES,$$

where b is width of the partition, m is mass of membrane per unit area, M is mass of membrane per unit length, F is friction of membrane per unit length, S is area of scala and E is elasticity per unit length. Equation (2.1) can be represented separately for the scala vestibula and scala tympani by using the subscript 'v' and't' respectively. Differentiating equation (2.3) twice w. r. t. time't', we get equation (2.4);

$$(2.4) \qquad b\frac{\partial^2 p}{\partial t^2} = \left(M\frac{\partial^4 S}{\partial t^4} + F\frac{\partial^3 S}{\partial t^3} + E\frac{\partial^2 S}{\partial t^2} \right).$$

The (equation of continuity for the cochlea)[12] , can be changed in such a form that the rate of change of the flow in the longitudinal direction x is equal to the velocity of volume displacement of the cochlear partition per unit length. Therefore this volume displacement is identical with the change of the cross-sectional area, we get.

$$(2.5) \qquad S_v\frac{\partial u_v}{\partial x} = -\frac{\partial S_v}{\partial t}, \qquad \text{(For scala vestibula)}$$

$$(2.6) \qquad S_t\frac{\partial u_t}{\partial x} = -\frac{\partial S_t}{\partial t}. \qquad \text{(For scala tympani)}$$

The membrane or partition is considered as incompressible, so that

$$(2.7) \qquad \partial S_v = -\partial S_t$$

and

$$(2.8) \qquad S_v\frac{\partial u_v}{\partial x} = -\frac{\partial S}{\partial t} = -S_t\frac{\partial u_t}{\partial x}.$$

It follows that

$$(2.9) \qquad \frac{\partial u_t}{\partial x} = -\frac{S_v}{S_t}.\frac{\partial u_v}{\partial x},$$

$$(2.10) \qquad \frac{\partial^2 u_t}{\partial x\,\partial t} = -\frac{S_v}{S_t}.\frac{\partial^2 u_v}{\partial x\,\partial t},$$

$$(2.11) \qquad E.S_v\frac{\partial^2 u_v}{\partial x\,\partial t} = -\frac{\partial^2 S}{\partial t^2}.E,$$

(2.12) $$F.S_v \frac{\partial^3 u_v}{\partial x \partial t^2} = -\frac{\partial^3 S}{\partial t^3}.F,$$

(2.13) $$M.S_v \frac{\partial^4 u_v}{\partial x \partial t^3} = -\frac{\partial^4 S}{\partial t^4}.M,$$

On adding above three equations, we get the following equations.

(2.14) $$S_v\left[M\frac{\partial^4 u_v}{\partial x \partial t^3} + F\frac{\partial^3 u_v}{\partial x \partial t^2} + E\frac{\partial^2 u_v}{\partial x \partial t}\right] = -\left[M\frac{\partial^4 S}{\partial t^4} + F\frac{\partial^3 S}{\partial t^3} + E\frac{\partial^2 S}{\partial t^2}\right].$$

Replace R.H.S. of above equation by using equation (2.4), we get following equation;

(2.15) $$b\frac{\partial^2 p}{\partial t^2} = -S_v\left[M\frac{\partial^4 u_v}{\partial x \partial t^3} + F\frac{\partial^3 u_v}{\partial x \partial t^2} + E\frac{\partial^2 u_v}{\partial x \partial t}\right].$$

Now differentiating eq. (2.1) w. r. to't', we get

(2.16) $$\frac{\partial p}{\partial x} = \frac{\partial p_v}{\partial x} - \frac{\partial p_t}{\partial x}.$$

According to fluid dynamics (M.D. Raisinghania) the equation of motion or rate of pressure change in the longitudinal direction for the scala vestibuli will be equal to

(2.17) $$\frac{\partial p_v}{\partial x} = -\rho\frac{\partial u_v}{\partial t}$$

And for the scala vestibuli will be equal to

(2.18) $$\frac{\partial p_t}{\partial x} = -\rho\frac{\partial u_t}{\partial t}.$$

On substituting these values in equation (2.16), we get;

(2.19) $$\frac{\partial p}{\partial x} = -\rho\frac{\partial u_v}{\partial t} + \rho\frac{\partial u_t}{\partial t}.$$

Again on differentiating above eq. w. r. t. 'x', we get

(2.20) $$\frac{\partial^2 p}{\partial x^2} = -\rho \frac{\partial^2 u_v}{\partial t\, \partial x} + \rho \frac{\partial^2 u_t}{\partial t\, \partial x}.$$

To eliminate u_t, from the above equation, we use equation (2.10) and then we get the following equation;

(2.21) $$\frac{\partial^2 p}{\partial x^2} = -\rho \frac{\partial^2 u_v}{\partial t\, \partial x} - \rho . \frac{S_v}{S_t} . \frac{\partial^2 u_t}{\partial t\, \partial x},$$

(2.22) $$E . \frac{\partial^2 u_v}{\partial x\, \partial t} = \frac{-E . S_t}{\rho .(S_t + S_v)} \frac{\partial^2 p}{\partial x^2}.$$

Differentiating Equation (2.22), w. r. to. 't' and replacing E by F, we get the following equation

(2.23) $$F . \frac{\partial^3 u_v}{\partial x\, \partial t^2} = \frac{-F . S_t}{\rho .(S_t + S_v)} \frac{\partial^3 p}{\partial x^2 \partial t}.$$

Again differentiating eq. (2.23) w. r. to. 't' and replacing F by M we get

(2.24) $$M . \frac{\partial^4 u_v}{\partial x\, \partial t^3} = \frac{-M . S_t}{\rho .(S_t + S_v)} \frac{\partial^4 p}{\partial x^2 \partial t^2}.$$

On adding above three equations (2.22), (2.23), and (2.24), we get the following equation

(2.25) $$\left[M \frac{\partial^4 u_v}{\partial x\, \partial t^3} + F \frac{\partial^3 u_v}{\partial x\, \partial t^2} + E \frac{\partial^2 u_v}{\partial x\, \partial t} \right] = \frac{-S_t}{\rho .(S_t + S_v)} \left[M \frac{\partial^4 p}{\partial x^2 \partial t^2} + F \frac{\partial^3 p}{\partial x^2 \partial t} + E \frac{\partial^2 p}{\partial x^2} \right].$$

On replacing the L.H.S. of equation (2.25), by using equation (2.15) we get the following equation;

$$-\frac{b}{S_v}\frac{\partial^2 p}{\partial t^2} = \frac{-S_t}{\rho.(S_t+S_v)}\left[M\frac{\partial^4 p}{\partial x^2 \partial t^2} + F\frac{\partial^3 p}{\partial x^2 \partial t} + E\frac{\partial^2 p}{\partial x^2}\right].$$

(2.26) $$b\frac{\partial^2 p}{\partial t^2} = \frac{S_v S_t}{\rho(S_v+S_t)}\left[M\frac{\partial^4 p}{\partial x^2 \partial t^2} + F\frac{\partial^3 p}{\partial x^2 \partial t} + E\frac{\partial^2 p}{\partial x^2}\right].$$

All cochlear theories use simple harmonic function, hence we can put

(2.27) $$p = P e^{iwt},$$

where $w = 2\pi f$ and f is frequency of oscillation.
Equation (2.27) implies that

(2.28) $$\frac{\partial^2 p}{\partial x^2} = \frac{\partial^2 P}{\partial x^2} e^{iwt},$$

(2.29) $$\frac{\partial^3 p}{\partial x^2 \partial t} = iwe^{iwt}.\frac{\partial^2 P}{\partial x^2},$$

(2.30) $$\frac{\partial^4 p}{\partial x^2 \partial t^2} = -w^2 e^{iwt}.\frac{\partial^2 P}{\partial x^2},$$

(2.31) $$\frac{\partial^2 p}{\partial t^2} = -w^2 P e^{iwt}.$$

Now by using equation (2.28), (2.29), (2.30), (2.31) and (2.26), we get the following equation:

$$-w^2 P e^{iwt} = \frac{S_v S_t}{b\rho(S_v+S_t)}\left[E - w^2 M + iwF\right] e^{iwt}\frac{\partial^2 P}{\partial x^2},$$

(2.32) $$w^2 P = -\frac{S_v S_t}{b\rho(S_v+S_t)}\left[E - w^2 M + iwF\right]\frac{\partial^2 P}{\partial x^2},$$

where $p = P(x)\, e^{iwt}$, $v = V(x)\, e^{iwt}$, $u_v = U(x)\, e^{iwt}$ is taken for pure tone.

Using, Kucharski's observation[13], F can be taken so small that iwF can be neglected and taking $E = w^2 M$, we get final equation which is

$$(2.33) \qquad W^2 P = -\frac{S_v S_t}{b\rho (S_v + S_t)} \cdot \frac{\partial^2 P}{\partial x^2},$$

As we know that cross-sectional area for scala vestibula and tympani can be taken equal, i.e. $S_v = S_t = S_0$.

$$(2.34) \qquad W^2 P = -\frac{S_0}{2b\rho} \cdot \frac{\partial^2 P}{\partial x^2},$$

Let $\alpha^2 = \frac{S_0}{2b\rho}$, then

$$(2.35) \qquad \alpha^2 \frac{\partial^2 P}{\partial x^2} + W^2 P = 0.$$

The above equation is a partial differential equation of the form $a_0 \frac{\partial^2 y}{\partial x^2} + a_1 \frac{dy}{dx} + a_2 y = f(x)$, where a_0, a_1, a_2 are constants.

Therefore general solution of equation (2.35) can be written as;

$$(2.36) \qquad P(x) = C_1 + C_2 e^{(-w^2/\alpha^2)x},$$

where, C_1 and C_2 are arbitrary constants. Therefore above relation might be used for calculating pressure difference across the basilar membrane for the frequency of various ranges (infrasound) and due to this pressure animal behave abnormally before earthquake. The length and width of basilar membrane varies acoording to animal, for example length of basilar membrane is 2.0 cm. 2.4 cm., 2.1 cm 3.2 cm. for cat, dog, guinea-pig and human respectively[14]. Therefore parameters for all these animals will be different these animals feel variation in pressure for a fix range of frequency of seismic waves. The above value of pressure will depend upon distance from stapes, and frequency of seismic pulse.

3. Conclusion

An endeavor has been made in the present study to estimate the pressure difference in the inner ear of animal due to seismic waves of very low frequency generated before an earthquake. Therefore sometime dog, cat, guinea pig, rat; mice, etc start to behave abnormally before earthquake. The paper has shown encouraging results of using abnormal animal behavior before an earthquake for prediction. It requires its due attention in Indian context, which may be used for earthquake prediction.

Appendix: A

S Area of scalas
ρ Density of fluid
c Velocity of sound in the cochlear fluid
b Width of the basilar membrane
u Velocity of fluid in x direction
v Vertical velocity of membrane
p Pressure difference across the basilar membrane
m Mass of the membrane per unit area
r Resistance of the membrane per unit area
k Stiffness or rigidity of membrane per unit area
M Mass of membrane per unit length
E Elasticity of the membrane per unit length
F Friction of membrane per unit length
x Distance of basilar membrane

References

1. Z. Guozhang, Some characteristics of animal behavior prior to earthquakes. In: Earthquake prediction, Terra scientific Publishing Company (TERRAAPUB), *Tokyo Unesco, Paris*, (1984) 246.
2. T. Rikitake, *Earthquake Prediction*, Amsterdam, the Netherlands: Elsevier Scientific Publishing Company, 1976.
3. N. Bhargava, V. K. Katiyar, M. L. Sharma and P. Pradhan, Earthquake prediction through animal behaviour– A review, *Indian Journal of Biomechanics*, (2009) 159-165.
4. A. A. Nikonov, Abnormal Animal Behavior as a Precursor of the 7 December (1988) Spitak, Armenia, Earthquake, *In Natural Hazards*, **6** (1992) 1-10.
5. Christine Kenneally, How did animals survive the tsunami?, Slate Magazine: Posted Thursday, Dec. 30, (2004), at 5:47 PM ET.
6. William K Tong, *Abnormal animal behavior and the prediction of earthquakes*: A Research Paper Presented to the Faculty of Department of Earth sciences, Northeastern Illinois University, 1988.
7. K. Musha and Jishin Namazu (Earthquake and catfish), *Toyotosho., Tokyo* (1957) 208.

8. S. Hatai and N. Abe, The Responses of the Catfish, Parasilurus ascotus, to Earthquake. *Proc. Imperial Acad. Japan*, **8** (1932) 374-378.
9. Emily Shepard, Animals of infrasound, *Physics of music fall* (2003) 1-5.
10. Could Your Pet Save Your life:© Life Positive, http://www.small-farm-permaculture-and-sustainable-living.com, (2006).
11. *Anatomy and Physiology of Animals-The Senses*, Wikibooks, open books for an open word, 2011.
12. L. C. Peterson and B. P. Bogert, A dynamical theory of cochlea, *Journal of the Acoustic Society of America*, **22(3)** (1950) 369-381.
13. W. Kucharski and Z. Physik., **31**(1930)264
14. J. A. Keen, *A Note on the Length of the Basilar Membrane in Man and in Various Mammals*, Department of Anatomy, University of Cape Town, (1940) 524- 527.