Journal of Asian Earth Sciences 54–55 (2012) 1–8

Contents lists available at SciVerse ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Review

Earthquake precursory studies in India: Scenario and future perspectives

Mithila Verma, Brijesh K. Bansal *

Geosciences Division, Ministry of Earth Sciences, Prithvi Bhawan, Lodhi Road, New Delhi 110 003, India

ARTICLE INFO

Article history:
Received 6 September 2011
Received in revised form 22 March 2012
Accepted 5 April 2012
Available online 30 April 2012

Keywords:
Earthquake prediction
Precursors
Multi-parametric observatories
Real-time analysis
Bore-hole investigations and predictive model

ABSTRACT

Earthquakes are the worst natural calamities that strike without any notice and cause immediate loss of life and property. Internationally, serious and scientifically acceptable earthquake prediction studies started in 1970s and short term prediction of the Heicheng earthquake of February 4, 1975 in China is a land mark. In India, a successful medium term prediction of August 6, 1988 earthquake, (M 7.5) in northeast Indian region encouraged to intensify such studies in the country. These predictions were based mainly on seismological precursors. Initially, the precursory studies were taken in isolated manner, but after validation of specific geophysical parameters, efforts were made to adopt an integrated approach involving collection, analysis and interpretation of various precursory observations in a comprehensive and coordinated manner. Accordingly, a few Multi-parametric Geophysical Observatories (MPGOs) have been established at the selected locations in seismically active areas in the country. This approach led to successful short term prediction of some moderate earthquakes ($M \geqslant 4$) in Koyna region (famous for Reservoir Triggered Seismicity) in western India. Simultaneously, efforts have been made to generate long term multi-parametric observations from these observatories, as a basic scientific input required for future earthquake prediction related studies. The real-time analysis of these data sets would help to understand the earthquake generation process and attaining the predictive capabilities by developing models for short term earthquake forecasting. To facilitate direct observations and test the hypothesis of Reservoir Triggered Seismicity (RTS) as well as to understand the earthquake generation processes, it is planned to undertake deep borehole (6–8 km) investigations in Koyna region of western India.

The paper highlights the efforts made so far in India in the area of earthquake precursory studies as well as the future road map.

Contents

1. Introduction 1
2. Earthquake precursors 2
3. Changing scenario of earthquake precursory research in India. 3
   3.1. Leads during eighties 3
   3.2. Leads during nineties 3
   3.3. Leads during turn of century 3
   3.4. Recent developments 4
4. Future directions 8
   Acknowledgments 8
   References 8

1. Introduction

The problem of predicting earthquake has always been on the horizon of seismology (Simpson and Richards, 1981; Rikitake, 1982; Lomnitz, 1994). As we are know, the earthquake is one of the worst natural calamities and unlike other natural events such as cyclones, floods and draughts strikes without any notice which not only cause immediate loss of life and property but also make a long term adverse impact on the overall economy of the country. There is no proven scientific technique available, as yet, to precisely forecast the occurrence of earthquakes in terms of space,

* Corresponding author.
E-mail address: bansalbk@nic.in (B.K. Bansal).

1367-9120/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jseaes.2012.04.003

time and magnitude. However, efforts are being made the world over to understand the physics of earthquake generation process and develop the predictive model. Efforts towards earthquake prediction were started about a century ago but, systematic research on this aspect started in early 1960s in countries viz. Japan, China, USA, Russia, etc. and peaked during 1970s, when a few successful attempts were made, like the August 3, 1973, Blue Mountain Lake earthquake of *M* 2.6 in New York based on the precursory change in the Vp/Vs ratio. This attempt was followed by another spectacular and accurate prediction of the February 4, 1975 Haicheng earthquake of *M* 7.3 in China based on intense foreshock activity and several other precursors, which saved about 100,000 human lives (Zongjin Ma et al., 1989). At the same time, pessimism was also prevailed among the geo-scientists due to some failure attempts like occurrence of the 1976, Tangshan earthquake of *M* 7.6 in China, for which no prediction could be made. Later, when the predicted earthquake did not occur within the specified time frame (1985–1993) in the Parkfield on San Andreas Fault and the 1995 Kobe earthquake (Mw 7.3) was failed, turned the collective hopefulness of the scientific community into pessimism.

In India, the story is not much different. After the successful medium term forecast of 1988 (*M* 7.3) earthquake in NE Himalayan region (Gupta and Singh, 1986), there was a lull period for quite some time. However, sporadic efforts continued till the first short term forecast of August 30, 2005 earthquake (Mw 5.0) made by (Gupta et al., 2005). This forecast was made based on nucleation pattern. Subsequently, several such forecast were made for Koyna region like 13 November 2005 (*M* 4.0), 26 December 2005 (*M* 4.2) and 17 April 2006 (*M* 4.7) based on nucleation process (Gupta et al., 2007). The success of short term forecast in Koyna encouraged intensifying such studies in the country. Accordingly, two multi-parametric geophysical observatories were established at Ghuttu in NW Himalaya and Shillong in NE Himalaya in 2007, with a view to examine the relationship between earthquake occurrence and different precursory signals.

More focused efforts are now being made to encourage the earthquake precursory research in the country with the ultimate goal of developing a predictive model. Ministry of Earth Sciences (MoES) has recently launched a National Program on Earthquake Precursors (NPEP) which primarily aimed at generating long term multi-parametric observations in the seismically active regions of the country, as a basic scientific input required for future earthquake prediction related studies. The real-time analysis of data from these observatories would help to understand the earthquake generation process and attaining the predictive capabilities by developing models for short term earthquake forecasting.

2. Earthquake precursors

Precursors are observables that are related to changes in physical conditions in the focal region (Udias, 1999). The subcommission of International Association of Seismology and Physics of the Earth's Interior (IASPEI) defined a precursor as a quantitatively measurable change in an environmental parameter that occurs before main shock and thought to be linked to the preparation of the main shock (Max Wyss, 1991). Enhanced foreshocks, seismicity pattern, hydrological and radon gas have been considered as few of the notable precursors in the recent times. Since 1970s, several advanced techniques based on land and space based observation like GPS-based geodesy, radar interferometry, and microgravity are being employed towards identifying possible earthquake precursors. However, no precursor has yet been discovered which acts as an infallible indicator for the future occurrence of an earthquake (Wyss and Booth, 1997). As a result of intensive monitoring, various precursory signals are reported which are broadly classified into the following categories:

(i) Seismological precursors.
(ii) Geochemical precursors.
(iii) Geomagnetic and geoelectric precursors.
(iv) Atmospheric/ionospheric precursors.
(v) Geodetic precursors.

Amongst all the precursors, seismological precursors are the most widely observed precursors and are the easiest to study because of the wealth of data in observatory catalogues, and the efficacy of modern seismograph networks. These include the Seismic wave velocities, Vp/Vs anomalies, Seismicity patterns like Seismic Quiescence and Swarm activity, Foreshocks, Source mechanism, Hypocentral migration, *b*-value, Shear-wave splitting, Stress modifications and Coda decay rate, etc. However, the seismicity pattern becomes noticeable. Other possible precursor that has received varying degree of attention over the past few decades is the geochemical changes in the epicentral region. It has been observed that the relative composition of crustal fluids and gases may alter appreciably preceding an earthquake occurrence. Such changes are enhanced in geothermal areas and in active fault regions. For strong earthquakes, like that of Kobe (1995), Haicheng (1975) and Tangshan (1976), there was increasing trend for radon and helium anomalies for a few months. Besides the Radon/Helium and other inert gases content, water level changes and discharge from wells, Chemical composition of water in bore holes, Temperature of underground water and Geochemical changes of fluids in the earth's crust are some of the geohydrological precursors which have been identified. Geochemical anomalies have been seen to occur as far as 100–500 km away from the epicenter for large/strong earthquakes. There could be distinct pattern for precursors as a function of time. The amplitude of precursor also depends on other parameters like epicentral distance and magnitude.

It is a well known fact that earthquake involves sudden release of strain, which accumulates over a period of several years. The careful monitoring of this strain accumulation in the seismically active areas will help in forecasting large earthquakes. Since shallow earthquakes may cause surface crustal deformation, it is imperative to assume that the released coseismic crustal deformation must have accumulated in the inter-seismic period, which would have caused crustal deformation. Hence, earthquake precursors based on ground deformation are considered important. The GPS based measurements of ground deformation provide evidence for strain accumulation which can be used as long term precursor, however, no evidence of existence of short term precursor is available yet.

Some changes in physical parameters that have been proposed as precursors have been justified theoretically in terms of the phenomenon called dilatancy. The stress-induced flow of fluids into dilatant zone of impending earthquake, due to the relative differences of mass of electrons and ions, produces charge separation and sets up streaming potential at the fluid-rock interface. This electrokinetic phenomenon in turn induces electric current producing observable changes both in electric and magnetic field at earth's surface (Mizutani et al., 1976; Fitterman, 1979; Dobrovolsky et al., 1989). The magnetic, electric and electromagnetic precursors represent a class of precursors that are claimed to have played a key role in successful prediction. In addition, it is also observed that pressure built-up due to seismic activity and associated subsurface degassing might create changes in thermal regime prior to an earthquake event and if this change is detected, it can provide very important clues about future earthquake activity. The studies revealed changes in land surface temperature of the order of 5–10 °C a few days before the