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Research note

Active Seismograph for Early Detection of Earthquake

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ABSTRACT
Passive seismographs can detect impending earthquakes only a few minutes before the occurrence of an earthquake. In contrast, active seismographs can detect impending earthquakes months in advance. As such they are better suited to issue necessary warning with sufficient time in hand to meet the disaster that the impending earthquake may bring about. Apart from activating the disaster management to get prepared to meet the eventuality by taking steps to minimise the risks to local population, civil constructions, buildings, water and power supplies, active seismographs are found most useful for shutting off operating nuclear power plants. Such an operation in time, in the region of impending earthquake helps to ward of any catastrophic situation due to uncontrolled nuclear radiations.

Active seismographs measure the response of subsurface geologic and tectonic features, which include changes in the rock properties under stress generated due to progressive increase in destabilising geologic forces.

A simple, yet effective, system of active seismograph is described, which can conveniently be set up and monitored.

INTRODUCTION

Earthquake monitoring has been an activity prevalent in human civilization from prehistoric times. From observing any abnormal behaviour of certain animals and birds to unexpected changes in the water levels of stagnant water bodies and certain astronomical configuration of planets have been used to make predictions on likely occurrence of impending earthquakes. Because of the damage to humans and their establishments due to earthquakes, dwellings for the habitation have been designed to soften the effects of damages due to them in areas of frequent earthquakes.
A brief account of human efforts to predict earthquakes in pre-historic times has been given by Ramanamurthy (2011) and also in the Introduction chapter of his paper by Reddy (2012).

The basic cause of earthquakes

All earthquake precursors are based upon the changes in the steady states of physical or chemical characteristics of the ground conditions of a locality. Such changes are invariably caused due to tectonically sustained or sporadic external or internal forces within the earth, leading to a breakdown of the stability of one or more firmer lithological strata in the earth's crust. Physical and chemical changes in the softer strata of the earth's crust, particularly those lying closer to the earth's surface have been a constant feature of the dynamics of the earth's crust, but have very little effect in creating any damage of significance to the flora and fauna on the surface of the earth, except when they occur in the sea. Here also, severe damage to the flora and fauna of the coastal land surface can occur, if the changes involve any firmer sub-sea lithological strata at shallow depths. Such changes often give rise to tsunamis, some of which may hit the coastal land areas with ferocious impact causing widespread damage to the land based flora and fauna of the coastal regions.

The small insignificant earthquakes which take place all the time in the land due to the physical and chemical changes in shallow softer beds of the earth's crust are a part of the weathering process of the skin of the earth's crust under the influence of the latter's dynamics. Such changes also take place all the time in the shallower depths of the sea bottom, and consequently giving rise to miniscule tsunamis, but their impact is lost in the larger wave dynamics caused by the external (wind and astronomical causes) factors and have never been considered as any stand-alone threat to the land fauna and flora.

Earthquake monitoring

Earthquakes have been conventionally monitored by a network of passive seismographs set up at vulnerable locations based upon the knowledge of past history and up-to-date geology and tectonics of the earth's crust. These passive seismographs record the tremors as and when they strike the seismographs. From the intensities (as measured in the Richter's scale) and the frequency of occurrence of such tremors, warnings to the population inhabiting the locality of occurrence of such tremors are issued to safeguard lives and property. Civil engineering codes are developed to be followed in the construction of buildings and other structures in any region or locality based upon its tectonic setting and past historical records of earthquakes. No prediction of any time when a disastrous earthquake event may overtake the population in a locality has been possible from the records of passive seismographs. In the case of tsunamis, though, the location of an earthquake, which gives rise to a dangerous tsunami, is rather precisely determined by the passive seismographs, and the speed of the tsunami towards the coastal regions can be computed from the application of hydrodynamic principles (which are generally adjusted according to other external influencing factors). This helps in giving advance warning of the disaster likely to occur in the coastal regions, including the times at which the tsunami would strike different coastal zones of land populated with human settlements.

Breakdown in normally stable status of a system in Nature is either due to an external impact or due to internal adjustments of the constituting elements. More often, the latter is the consequence of sustained external impacts of very small magnitudes over very long periods of time. The dynamics of the tectonic plates of the earth's crust coupled with the fluid flow within the rocks of the crust and the chemical changes of such rock fluids destabilise the apparent physical status of the rocks which otherwise provide the crust its apparent firmness. These physical changes in the stability providing rocks of the crust take place slowly over geologic times. After sustaining such internal impacts over certain duration of geologic time, the internal stability of such rocks slowly and progressively starts yielding to these impacts, till it is no longer able to hold and breaks down. The period of progressive changes in the stability of the rock system providing the firmness to the crust can be used to provide sufficient advance warning about the impending breakdown of the rock system, which gives rise to damaging or catastrophic earthquakes. Passive seismographs have not been able to record the hints of these progressive changes in the stability conditions of the rocks, sufficiently in advance to take all necessary precautionary measures to contain the ill effects of the main earthquake (due to breakdown of the stability of concerned rocks). Active seismographs aim to fill this gap.

Principle of Active seismographs

Changes in the stability conditions of the principal category of rocks can be monitored by frequently interacting with the possible physico-chemical changes taking place in any suspected earthquake area. The frequency of monitoring these conditions may vary, six months to start with. Frequency of monitoring is increased, if and when the changes appear to progressively gaining prominence. Geochemical seismographs are one such category of active seismographs, which are designed and used to give advance warning of the impending earthquakes. However, the changes in the geochemical signals from the earth are masked with unstable near-surface geochemical imprints, which make it very difficult to extract any reliable information about the impending earthquake of significance to human society months in advance.

As passive seismographs or active geochemical sensors fail to meet the requirement of predicting the likely occurrence of any severe earthquake months in advance, search for geophysics based active seismographs, which are sensitive and reliable in making such advance prediction has been going on in different research laboratories of the world. One of the most reliable geophysical mechanisms to interact with the status of the principal rock system of the crust has been the seismic signal. Advances in the shaping, analysing and monitoring of seismic signal have been made in a fast pace, due to its efficacy and reliability in monitoring the production of hydrocarbons from complex subsurface reservoirs. Hydrocarbon production has advanced from the conventional sandstone limestone reservoirs to shale. Seismic (including microseismic) signals have been found to be very useful not only in understanding the physical characteristics like, porosity, permeability, faults and fractures of the rocks, but also in identifying the weak zones (based upon their stress bearing properties) of rocks, which can be fractured with low intensity impacts. Advances in the monitoring and extraction of a shaped seismic signal, which is morphed due to its interaction and traverse through media of varying geophysical properties has helped not only in retrieving the desired signal but also to understand the physical characteristics of the media traversed by the seismic signal leading to its morphed form. This technology can be applied successfully to monitor the impending higher magnitude earthquakes months in advance, an aspect desired since long and which can be put to practice.

Research in the subject of Active seismographs

Laboratory research on the nature of progression of tectonic faults in the Centre for Geomechanics, Geofluids and Geohazards of Pennsylvania State University, USA in repetitive, slow stick-slip in serpentanite fault zones has led to the understanding of transition from stable to unstable frictional behaviour and its reverse process in stick-slip (as well as strike-slip) faults with the objective of monitoring and limiting the speed of slow earthquakes. The experiments have documented reduction of P-wave speed within the active sheer zone before the occurrence of stick-slip events. The researchers have concluded that if similar mechanisms operate in nature, higher resolution studies of elastic properties in tectonic fault zones might aid in the search of reliable earthquake precursors (Kaproth and Marone, 2013).

Another set of laboratory experiments by French and American universities aiming at the generation of deep focus earthquakes (400 – 700 kms) due to olivine –to-spinel transition in cold subducting lithosphere under differential stress at high pressure (2-5 gigapascals) and within a narrow temperature range (1000 to 1250 kelvin), generating nucleated fractures in the subducting slab, which propagate dynamically at a fraction of the shear wave velocity, leading to intense acoustic emissions that obey Gutenberg-Richter law without following Omori's law (Schubnel et al, 2013).

Proposed system of Active seismographs

Since the instability of the principle suite of rocks holding the crust is caused due to faults (vertical, oblique, strike-slip or a combination of these) and the faults are generated due to progressively increasing stress in them, by monitoring the changes in the measurable attributes of any set of well designed seismic signal incident on them, over a period of time (or, from time to time) a reliable prediction of impending earthquake can be made by suitably locating active seismographs on the surface. The locations may be chosen over mapped major faults, boundaries of tectonic plates, sites of important industrial installations, monuments and densely populated cities. In particular, all nuclear reaction sites need to be suitably covered with a network of active seismographs so that in the event of a warning about an impending earthquake, its activities are systematically deactivated and the plant is shut down and held on control to avoid any major nuclear disaster, whose effect might be suffered by the inhabitants over generations.

The proposed active seismograph has two components; (1) Actuator and (2) Receiver. Both of them are mounted on firm and stable separate platforms about 30m apart. The platforms are isolated from the vibrations from the

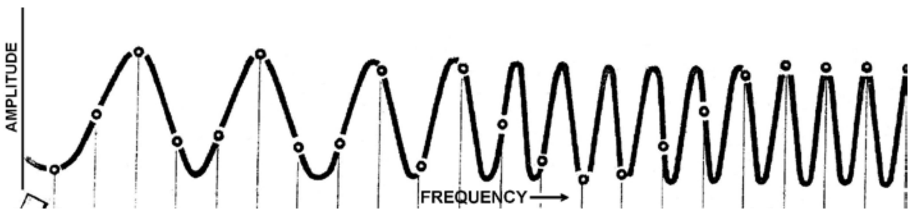

Figure 1. The Actuator is a heavy metal plate vibroseis signal producer of a sweep of frequency 2-60 cps in 15-20 sec duration (not to scale)

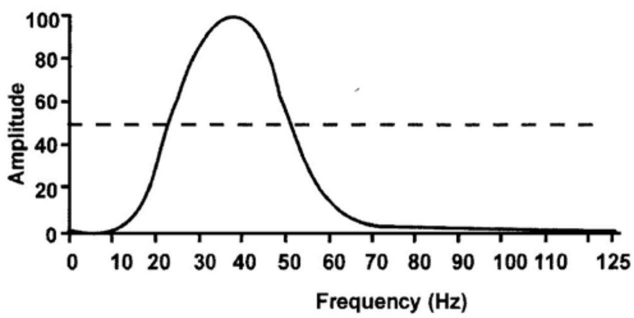

Figure 2. The records of the amplitude spectrum, at various Receiver locations (not to scale)

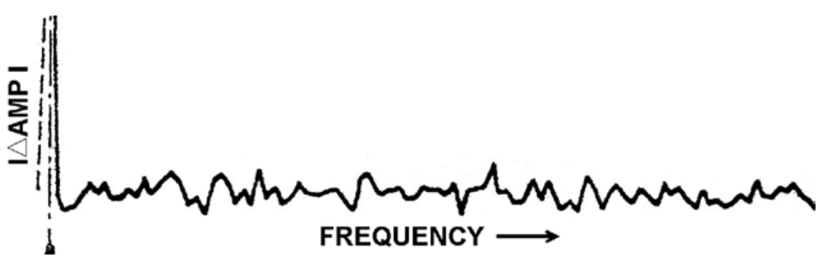

Figure 3. The difference between the two recordings of amplitude spectra taken at interval of 5-6 months .It is almost a straight line parallel to the frequency axis (not to scale).

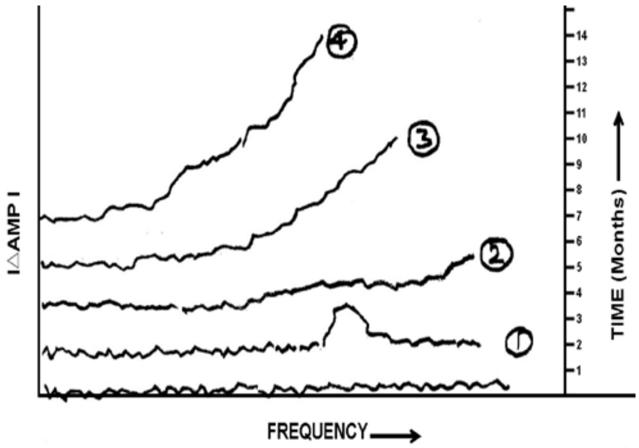

Figure 4. The sequence of vibroseis sweep is repeated at progressively shorter time intervals .The anomalies in the amplitude spectra from the recordings at different Receiver locations exhibit a progressive increase. The spacing between the traces on the month ordinate (on the right) may correspond as per scale of the TIME (Months) as follows; between the 0-axis trace and trace no. (1): 2 months, trace nos. (1) and (2): 6 months, trace nos. (2) and (3): 4 months, trace nos. (3) and (4): 2 months. (P.S: Amplitude spectra characteristics are presented , to bring out with clarity importance of the technique. The spectral details are not drawn to the scale).

surrounding ground up to a depth of 5m using special sound absorbing rubberised material providing firm hold on the platforms from sides, leaving the communication of seismic waves to and from bottom side only.

The Actuator is a heavy metal plate vibroseis signal producer of a sweep of frequency 2-60 cps in 15-20 sec duration (Fig. 1). The Receiver consists of a 3-component seismograph with a system of recording the received P and S seismic waves in film, magnetic tape or paper with marked time lines in seconds based upon a regulated speed of Recorder. The Recorder is actuated by a coded signal from any Actuator located at the same site or at a different site located several kms away from it. The signal code identifies the Actuator's location as well as the date and time of the initiation of the seismic sweep signal from it. Correspondingly, on receipt of the coded signal from any Actuator, all Recorders of Receivers are energised and the date and time of their respective initiation of recordings get recorded on the records being made by them. The schedule of actuation from each Actuator location is drawn up in such a manner that the time interval between the actuating sequences is normally 5-6 months, except when the first hint of a possible occurrence of an earthquake is noticed in any one or more Receiver locations. Thereafter, the time interval of actuating sequences can progressively be reduced to 4, 3, 2 and 1 month and shorter if the possibility of the occurrence of an earthquake gets reinforced based upon the analyses of the records of actuated vibroseis sweeps at various Receiver locations. From the records of seismic signals received at various Receiver locations, the amplitude spectrum (Fig. 2) and the speeds of the P and S waves recorded at each receiver location are determined. This is compared with the amplitude spectrum and speeds of P and S waves obtained from the next excitation of the same Actuator location obtained after 5-6 months. If the difference between the two recordings of amplitude spectra taken at interval of 5-6 months is almost a straight line parallel to the frequency axis (Fig.3), and the speeds of P and S seismic waves remain constant, the onset of any earthquake is discounted. On the other hand, if any departure, however small (and which cannot be attributed to any instrument or other localised reason - the latter can be discounted if the same is observed in more than one Receiver location) is taken as a hint of change in the stress regime of the principal rock bed/beds of the crust under scrutiny, leading to possible earthquake. The sequence of vibroseis sweep is repeated at progressively shorter time intervals and if the anomalies in the amplitude spectra from the recordings at different Receiver locations progressively increase (Fig.4), the occurrence of an earthquake due to the failure of the principal rock sequence in the earth's crust would be considered a positive deduction. Any corresponding change in the P and S seismic wave speeds (particularly, S wave speed) can be taken as a confirmation of the same deduction.

Using the set of Active seismographs at suspected earthquake vulnerable locations as described above, the likely occurrence of an earthquake can be predicted months in advance. Necessary disaster prevention measures can be taken in time to minimise the damage to important installations and human habitations.

REFERENCES

Kaproth, B.M. and Marone, C., 2013. Slow Earthquakes, Preseismic Velocity Changes, and the Origin of Slow Frictional Stick-Slip Instabilities; Science, v. 341, no. 6151, pp: 1229-1232.

Ramanamurthy, M.V., 2011. Earthquake Prediction Research and Pre-Disaster Management Strategy, International Journal of Earth Sciences & Engineering, v. 4, no. 6, pp: 941 – 946.

Reddy, P.R., 2012. Historical Development of Seismic Imaging Technique – An Overview; Journal of Indian Geophysical Union, v. 16, no. 3, pp: 71-86.

Schubnel, A., Brunet, F., Hilairet, N., Gasc, J., Wang, Y. and Green II, H.W. 2013. Deep-Focus Analogs Recorded at High Pressure and Temperature in the Laboratory; Science, v. 341, no. 6152, pp: 1377-1380.