Development of a new approach for earthquake prediction– Load/Unload Response Ratio

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The lithosphere is a very complex nonlinear system. Earthquakes occur in it. The physical essence for process of preparation and occurrence of an earthquake is precisely the process of the damage and failure (instability) of the local lithosphere which contains a series phenomena, such as nucleation , growth and coalition of micro-cracks (micro-quakes), dislocation, friction and rupture etc(Bai et al. ,1994). Many key problems of this process are still open at present.

If neglecting its detail, usually we can track the process by its constitutive relation. Instead of the stress and strain, we use the terms of load (P) and response (R). At first two parameters response rate (X) and Load / Unload Response Ratio (LURR) denoted be Y are defined as following. The response rate X is defined as

$$X = \frac{\Delta R}{\Delta P} \quad . \tag{1}$$

We further defined the response ratio as

$$Y = \frac{X_+}{X_-} \quad , \tag{2}$$

where X_+ and X_- denote the response rate for loading and unloading condition respectively.

It is well known that $X_+ = X_-$ so that $Y = 1$, for any linear systems. However the Y value does not keep on unvarying but depends on the state for a non-linear systems. For the situation for seismogenic system, $Y = 1$ as the local media are under very low stress level and fall in elastic condition, but $Y \geq 1$ as long as the local media fall in the damage regime and $Y \to \infty$ as soon as the focal media reaches the P_{max} point. Therefore the Y value can measure the closeness degree of the seismogenic system to instability . Since earthquake and many other geological disasters such as landslip, rock burst, volcanic eruption, etc. are instability of the rock with different sizes, so that the LURR theory could open a new way to prediction of such kinds of geological disasters.

There are several main problems to be solved in order to predict earthquake by means of the LURR theory, such as how to load and unload a block of crust, how to distinguish loading from unloading and which parameter or parameters is suitably adopted as response for LURR theory.

(1) How to load and unload a block of crust?
The linear size of seismogenic volume may reach hundreds even thousands kilometers. It can not be realized artificially at present to load or unload such a big "specimen". Fortunately Nature give us such means, that is the earth tide. Tide-generating stress varies periodically, hence it loads and unloads every point of the lithosphere periodically.

(2) With what criterion to distinguish loading from unloading?
A proper criterion should be adopted according to the physical essence of the specified problem. For example, Tresca criterion ($\tau_{max} = c$) and Von Mises criterion ($\tau_{oct} = c$) are available for metal. The nonlinearity of the constitutive relation for rock material is induced crucially by the nucleation, initiation, growth and coalition of cracks with different size so that the Coulomb criterion is more applicable to rock mechanics.

With Coulomb criterion loading can be distinguished from unloading by means of the sign of the increment of effective shear stress τ_e

$$\tau_e = \tau_n - f\sigma_n \quad , \tag{3}$$

where $\tau_n$andσ_n are the shear stress and normal stress (tensile stress refers positive) acting on the specified section respectively and f is the internal friction coefficient .

The remained problem is which parameters are suitable as the responses R. A lot of geophysical parameters, such as the crust deformation, level of well water and other seismic parameters can be chosen as responses for measuring Y. We are carrying out a quite big project cooperating with some Chinese geophysists in the fields mentioned above . In this paper, only the results of seismic energy which adopted as R to calculate Y are presented. Y is defined as :

$$Y = \frac{\sum_{i=1}^{N_+} E_i^m}{\sum_{i=1}^{N_-} E_i^m} \quad , \tag{4}$$

where E is the seismic energy, $m = 0$ or $1/3$ or $1/2$ or $2/3$ or 1 (in this paper m=1/2). Sign "N_+" denotes the number of earthquakes in loading period and "N_-" for unloading. For a given region (say $1^\circ \times 1^\circ$) and a given time window (say several months), Y value can be determined according to expression (4). Then the dangerous degree of an imminent earthquake in this region could be estimated in terms of the Y value.

Retrospective examination

Using the abundant seismic data of China and outside China, the theory of LURR has been examined comprehensively. The examined cases reached hundreds cases, including most earthquakes ($8 > M \geq 7$) occurred in the Chinese Mainland (few cases could not study for the reason of data) from 1970 to present, most strong earthquakes ($7 > M \geq 6$) occurred in northern China from 1970 to present and some strong or large event ($M > 6$) occurred in California, USA, Kanto region, Japan and Armenia, CIS. For more than 80 percent studied cases the values of Y increase and are significantly larger than 1. The duration of $Y > 1$, range from several months to several years and related to the magnitude.

As a contrast, we chose 7 stable regions with low seismicity in China and analyzed their variations in Y during two decades (1970-1992). The results contrasts sharply with the results before the impending strong earthquake . For all the seven regions, their Y values always fluctuate slightly about 1 during the whole two decades.

It is suggested from above result that Y value indicates the closeness degree to instability for a region indeed and the LURR theory could be adopted as a new approach to earthquake prediction.

Tentative practice for earthquake prediction in terms of LURR

In recent years a lot of earthquakes have been predicted beforehand by means of LURR, including ten odd strong earthquakes occurred in China as well as the Northridge earthquake (Ms 6.6,Jan.17,1994, USA). And an earthquake occurred in Kanto region, Japan (M 6.6, Sep.11, 1996, 35.5°N, 140.9°E) (X.C.Yin, et al, 1996).

The verification of LURR theory

In order to verify the LURR theory besides of the practice of earthquake prediction, a series fracture experiments for rock specimens (Y. C.Wang et al. 1998) and numerical simulation with discrete model (Y. C. Wang et al. Working group 1 in this workshop) have been conducted. The results of both indicate that the Y values are near 1 when the stress lower than the elastic limit and Y values increase with the enhance of stress and are markedly higher than 1 before the specimen breakdown.

Probability of LURR

This problem takes into account how the random factors influence the values of LURR. Assume that earthquakes occur according to Poisson models, i.e.each of them has equal probabilities to be a loading earthquake or an unloading one, with a constant rate, their magnitudes can be described by the Gutenberg-Richter law, and confidence intervals for LURR can be calculated. Those confidence intervals are helpful to make a judgment if an anomaly occurs.

The results show that the variation of LURR is controlled by the occurrence rate for the Poisson model, the b-value in the Gutenberg- Richter law and power m for the energy in calculating the Y value. The variance of LURR is an increasing function of m or a decreasing function of occurrence rate and b value.

The calculation is carried out by million of simulations. Finally the 0.90, 0.95 and 0.99 confidence bands from the p.d.f. of LURR have been found.

Having Bayes formula, now we can calculate the probability of earthquake prediction in terms of LURR

New developments

(1) Besides the seismic energy, other geophysical parameters such as velocity ratio, level of underground water, crust volume strain, coda wave attenuation etc. have been adopted as the response of LURR and the results are satisfying and interesting.

(2) Some researches suggested that LURR could be applied to the prediction of other disasters such as R.I.S , M.I.D. and landslide.

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