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Load-unload response ratio and its application to estimate future seismicity of Qiandao Lake region

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Abstract

LURR (Load-Unload Response Ratio) has been introduced briefly in this paper and future seismicity of Qiandao Lake region has been predicted in terms of LURR for the purpose of SFT (Submerged Floating Tunnel) project.

Keywords: LURR (load-unload response ratio); Qiandao Lake region; estimation of future seismicity

1. Introduction

The earthquake, a natural phenomenon which causes much massive destruction, can bring about lots of casualties and losses of properties and to predict the time, location and magnitude of the earthquake is one of the best ways to mitigate earthquake disasters. So earthquake prediction has much important practical significance. The seismogenic process is very complex, but from the viewpoint of mechanics, its physical essence lies in the damage process of the focal media which is a mechanical process [1]. Based on the thoughts above, Yin et al. [2-12] putted forward the method of Load-Unload Response Ratio (LURR) which can depict quantitatively the extent to which the focal media is approaching instability.

From macroscopic perspectives, the mechanical behaviors of a certain material can be comprehensively described by the constitutive curve (In Fig. 1 the ordinate denotes general load P and the abscissa is the response R to p and they are stress and strain respectively in one-dimensional stress-strain state.) If a material is loaded gradually it will endure regimes of elasticity, damage and failure in succession. What characterizes the elastic phase is its reversibility namely the loading and unloading processes are reversible. On the other hand, it is irreversible for the phase of damage in which it behaves distinctly under loading and unloading conditions and just on this disparity between loading and unloading processes we base the theory of LURR [1-6]. In the theory of LURR we need to define two parameters at first. One is response rate defined as

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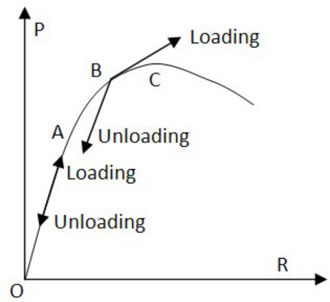

Fig. 1. Constitutive curve of the rock material

$$X = \lim_{\Delta P \to 0} \frac{\Delta R}{\Delta P} \tag{1}$$

The other is load-unload response ratio which is defined as

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

where X_+ and X_- refer to the response rate under loading and unloading conditions respectively. For the elastic phase, the response rate X_+ (under loading) = X_- (under unloading), hence Y=1. But $X_+ > X_-$ happens when the load exceeds the elastic limit, hence $Y > 1$. When the system approaches instability we get $Y \to \infty$.

Above all, it can be easily seen that the value of LURR, namely Y can depict quantitatively the extent to which the focal media approaches instability, and may bring about a new path for the prediction of geological disasters. However, to apply LURR to the prediction of earthquakes, there are several main scientific problems to be solved. One of them is how to load and unload a block of crust and how to distinguish loading from unloading. Another one is to choose a suitable parameter as the response for LURR theory.

(1) How to load and unload a block of crust.

The linear dimension of a seismogenic zone may reach hundreds even thousands of kilometers. One of the means to load and unload is by the earth tide. Tidal force varies periodically, so the induced stresses in the crust has been loading and unloading it periodically.

(2) How to distinguish loading from unloading.

To distinguish loading from unloading for rock materials, we resort to the Coulomb failure criterion [13-15]. It can be expressed as follow

$$CFS = \tau_n + f\sigma_n \tag{3}$$

where f, τ_n and σ_n denote the friction coefficient, shear stress and normal stress in the fault plane (with normal n) respectively. It is defined as loading when $\Delta CFS > 0$ and on the contrary as unloading when $\Delta CFS < 0$.

(3) The last question is deciding which parameter to choose as the response R for calculation of the value of LURR.

Here, we choose the energy of earthquakes as the response R and define LURR as

$$Y_m = \frac{\left(\sum_{i=1}^{N^+} E_i^m\right)_+}{\left(\sum_{i=1}^{N^-} E_i^m\right)_-} \tag{4}$$

where E is the seismic wave energy, m=0 or 1/3 or 1/2 or 2/3 or 1, the sign "+" denotes loading and "-"unloading. When m=1, E^m is exactly the energy itself; m=1/2, E^m denotes the so-called Benioff strain; m=1/3, 2/3, E^m represent the linear scale and the area scale of the focal zone respectively; m=0, E^m is the number of the earthquakes. N+ and N- are the numbers of earthquakes on loading and unloading conditions respectively. In this paper we adopt m=1/2. According to lots of researches, it is found that the general evolution law of LURR before an earthquake is: the value of Y becomes abnormal, climbing up to its peak, and then it begins to decrease to a normal level and finally the earthquake happens. A typical evolution curve of LURR is shown in Fig. 2.

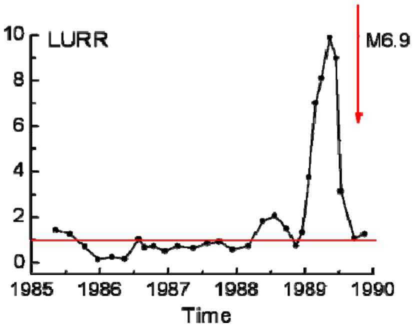

Fig. 2. Evolution of LURR before the Southern California earthquake in 1989

2. Studies of historical seismicity and analyses of LURR in Qiandao Lake region

2.1. Studies of historical seismicity in Qiandao Lake region

Qiandao Lake, a famous place for tourism which subordinates to Chun'an County, is located in latitude 29°11′-30°02′N and longitude 118°20′-119°20′W. Here the future seismicity in Qiandao Lake region is evaluated with the model of LURR and first there are some researches into the historical seismicity in Qiandao Lake.

According to "China earthquakes catalog" edited by China Earthquake Networks Center, we can see that there is a very low level of seismicity in Qiandao Lake region. The area with a center in latitude 29.61°, longitude 118.83° and with a radius of 100km has never seen an earthquake with magnitude more than M5 since 1831BC and any earthquakes with magnitude more than M4 since 1970. Furthermore, there wasn't any record of earthquake with magnitude more than M4 within a broader region with a radius of 150km. Fig. 3 shows the earthquake series (more than M2) in Qiandao Lake region with the same center and a radius of 150 KM. In terms of seismic intensity, it falls into the weakest class which is less than VI [16], so Qiandao Lake also belongs to areas with low seismic intensity.

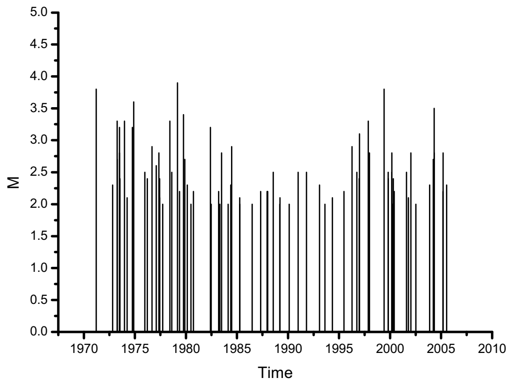

Fig. 3. Earthquake series in Qiandao Lake region

2.2. Analyses of the historical seismisity in Qiandao Lake region

To analyze the historical seismicity of Chinese mainland, we deduce the distribution of average released energy (called E_a) of earthquake wave by calculating the energy of earthquake wave between 1 Jan, 1900 and 31 Dec, 2009. E_a describes average historical seismicity for a specific circle region with centre (X_0, Y_0) and radius R which is defined as

$$E_a = \frac{\sum_{i=1}^{K} 10^{(4.8+1.5M_i)}}{N\pi R^2} \tag{5}$$

here M_i is the magnitude of the i-th earthquake while K denotes the number of earthquakes within the specific circle region. The relation between the energy of an earthquake and its magnitude is as follow

$$\log E_s = 1.5M_s + 4.8 \tag{6}$$

where M_s and E_s refer to the magnitude and energy (joule) of the seismic wave in question respectively. Here N is set to be 110 and R to be 200km, since we use the catalog from 1900 to 2009 amounted 110 years. So E_a means average energy emitted by seismic wave per square kilometer in that particular location annually. The distribution of E_a is shown in Fig. 4 in which the energy is transferred to the magnitude of earthquakes.

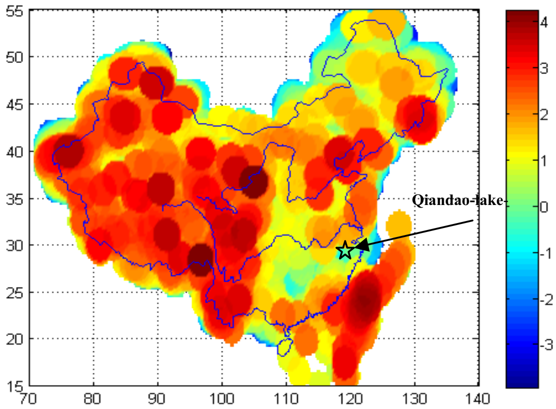

Fig. 4. Spatial distribution of Ea in Chinese mainland, , here abscissa and ordinate are longitude and latitude respectively

If E_a is calculated by the following formula

$$E_a^{'} = \frac{\sum_{i=1}^{K} 10^{(4.8+1.5M_i)} \cdot \left(\left(R - r_i\right)/R\right)^2}{N\pi R^2} \tag{7}$$

then $E_a^{'}$ here means average energy emitted by seismic wave in that particular circle region with radius of 200km annually. The distribution of $E_a^{'}$ is shown in Fig. 5 in which the energy is transferred to the magnitude of earthquakes.

It can be seen from Fig. 4 and Fig. 5 that historical seismicity in Qiandao Lake region is very low and significantly lower than other areas in China.

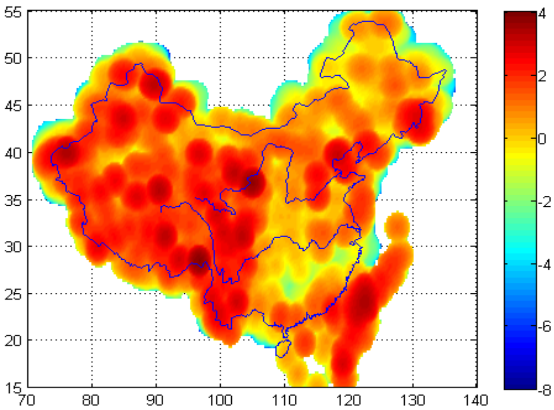

Fig. 5. Spatial distribution of Ea ′in Chinese mainland, here abscissa and ordinate are longitude and latitude respectively

2.3. Analyses of seismicity in Qiandao Lake region by LURR

If we apply LURR model to analyses in Qiandao Lake region with spatial window at 200km and time window at 60 months, then the deduced evolution curve of LURR is shown in Fig. 6. We can see from the chart that the value of LURR namely Y has been below 1, so the area of Qiandao Lake will be at the stage of low level of seismicity.

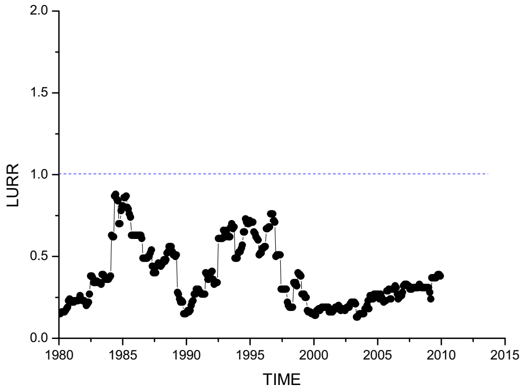

Fig. 6. Evolution of LURR in Qiandao Lake region

3. Conclusion

Qiandao Lake region has been with a low level of seismicity, where it has never seen any destructive earthquake; the value of LURR in the region has been below 1. So the chance that there occur destructive earthquakes is very low.

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