Study on Spatial and Temporal Variation of LURR in Southern California and Its Implication for Earthquake Tendency in This Region

Yongxian Zhang[1], Xiangchu Yin[1,2] and Keyin Peng[1,2]

(1) The Center for Analysis and Prediction, China Seismological Bureau, Beijing 100036, China(e-mail: zhang.yongxian@263.net, phone: +86-10-88015551; fax: +86-10-68218604; e-mail: yinxc@btamail.net.cn, phone:+86-10-88015574, fax: +86-10-68218604; e-mail:peng_keyin@163.com, phone: +86-10-88015547; fax: +86-10-68218604;). (2) LNM, Institute of Mechanics, Chinese Academy of Sciences, Beijing, 100080, China(e-mail: yin@lnm.imech.ac.cn, phone:+86-10-62545533 ext. 3004)

Abstract

Based on the theory of LURR and its recent development, the spatial and temporal variation of LURR in the Southern California region from 1980 to 2001 was studied in this paper. The Southern California region is divided into 11 parts according to its fault system and stress field. With uniform parameters for time and space windows, the scanning results show that obvious LURR anomalies occurred before 5/6 of the earthquakes considered. The strong earthquakes considered are magnitude 6.5 and greater. The critical regions of LURR are near the epicenters of the strong earthquakes and the LURR anomalies occur months to years before the earthquakes. The earthquake tendency in the California region is discussed in this paper according to former earthquake cases.

Keywords: LURR, stress field, spatial and temporal scanning, Southern California Region, earthquake tendency.

Introduction

The Load-Unload Response Ratio (LURR) method, put forward by Yin X.C.(1987[1]), has been tested in many regions in China and some regions in America, Japan and Australia. The method has shown considerable promise for medium-term earthquake prediction [2-5].

The physical essence of an earthquake is the failure or instability of the focal media. When a seismogenic system is in a stable state, its response to loading is nearly the same as its response to unloading, whereas when the system is in an unstable state, the responses to loading and unloading become quite different(1-4). LURR (Load/ Unload Response Ratio) is defined as

$$Y = X^+ / X^-, \tag{1}$$

where X^+ and X^- are the response rates during loading and unloading according to some measure. According to the LURR idea, when a seismogenic system is in a stable or linear state Y ~ 1 whereas when the system lies outside of the linear state $Y > 1$. In earthquake prediction practice with LURR, loading and unloading periods are determined by calculating perturbations in the Coulomb Failure Stress induced by earth tides. Experimental and numerical simulation have validated LURR[6-10]. In retrospective studies, high *Y* values have been observed months to years prior to most events and some successful intermediate-term earthquake predictions have been made [4].

In this paper, we studied LURR variation in the Southern California region from 1980 to 2001 using a spatial and temporal scanning method. The draft framework of the fault system and stress field for Southern California is obtained from the SCEC (Southern California Earthquake Center) Data Center via INTERNET. The earthquake catalogue used in this paper is from the CNSS (Council of the National Seismic System) via INTERNET.

Method to Calculate LURR

Calculation of LURR

In LURR theory, *Y* is defined directly by the seismic energy as follows:

$$Y_m = \frac{[\sum_{i=1}^{N^+} E_i^m]_+}{[\sum_{i=1}^{N^-} E_i^m]_-} \tag{2}$$

Where *E* denotes seismic energy which can be calculated according to the Gutenberg-Richter formula [11-12], the "+" sign means loading and "-" means unloading, m=0 or 1/3 or 1/2 or 2/3 or 1. When m=1, E^m is exactly the energy itself; for m=1/2, E^m denotes the Benioff strain; for m=1/3, 2/3, E^m represents the linear scale and area scale of the focal zone, respectively; for m=0, Y is equal to N^+ / N^-, and $N+$ and N^- denote the number of earthquakes which occur during the loading and unloading periods.

In this paper, *m* is chosen as 1/2, which means that *Y* is determined by Benioff strain during the loading period over the unloading period.

Since the preparation and occurrence process of earthquakes is controlled not only by deterministic dynamical law but also affected by stochastic or disorder factors, Zhuang and Yin(1999[13]) studied the influence of random factors on LURR in order to judge whether a high Y value can be considered an earthquake precursor within a specified confidence level. They gave the critical value of LURR Y_c that depends on the number of earthquakes under different specified confidence levels. For instance, at the confidence level of 90%, Y_c is equal to 3.18 if the number of earthquakes in the time and space window is 20, which means that Y should be equal to or greater than 3.18 when the number of earthquakes is

20. For the confidence level of 99%, Y_c is 7.69 if the number of earthquakes in the specific time and space window is 20. The greater the earthquake number is, the lower the Y_c (critical LURR).

In this paper, we give the critical region of LURR by Y/Y_c instead of Y under a confidence level of 99%.

Determination of loading and unloading

Loading and unloading periods are determined by calculating perturbations in the Coulomb Failure Stress (CFS)[e.g., 14-15] induced by earth tides.

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

where σ_n stands for normal stress, τ_n denotes shear stress, f is the coefficient of internal friction, and $\boldsymbol{n}$ is the normal of the fault plane on which *CFS* reaches its maximum. When the increment of Coulomb Failure Stress (ΔCFS) is positive, it is in a loading state; otherwise, when ΔCFS is negative, it is in an unloading state.
Since the resultant stress, σ_{ij} in the crust consists of tectonic stress σ^T_{ij} and the tide induced stress σ^t_{ij}, and the level of σ^T_{ij} (on the order of $10^6 – 10^8$Pa) is higher than the level of σ^t_{ij} ($10^3 – 10^4$Pa) the directions of the principle resultant stress in the crust and the direction of n can be determined from the tectonic stress only. However, the rate of change of the tidal induced stress is much larger than that of the tectonic stress[16], thus ΔCFS is mainly due to tidal-induced stress, which can be calculated precisely.

Tectonic stress field in Southern California

An outline of the stress field in Southern California can be obtained from the world stress map (Zoback, M. L., 1992[17]). The stress field is supplemented by the fault system in Southern California which is provided by SCECDC (Southern California Data Center). With these two sets of information, we divided the Southern California region into 11 unit areas with uniform stress fields in each area (figure 1).

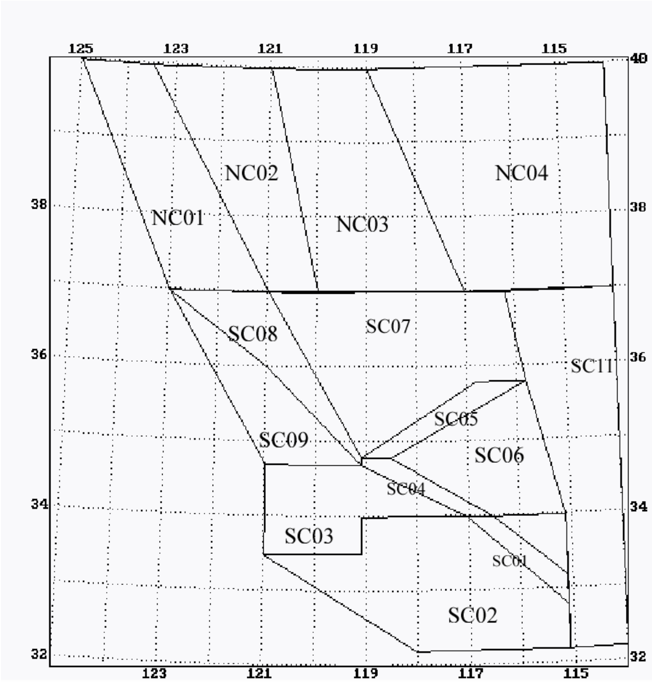

Figure 1 Division of Southern California

Data and Scanning Parameters

The earthquake catalogue we use in this paper is from CNSS (Council of the National Seismic System).

In order to speed the calculations and avoid disturbance from outstanding earthquakes, we chose magnitude thresholds according to the Gutenberg-Richter relation in each unit area.

The scanning parameters are as follows:

Time window: 1 year

Time moving step: 3 months

Space window: R=100km

Space moving step: 0.25 ° in latitude and longitude direction

That is, a circle region with radius 100 km was selected as the spatial window within which to calculate a value of Y / Y_c (LURR/critical LURR) for a specific time window (1 year), then the circle center was moved step by step in both latitude and longitude by increments of 0.25 degrees.

Results and discussion

Y/Y_c before six strong earthquakes in Southern California

Our result show that obvious Y/Y_c anomalies occurred 1-2 years before five of the six strong earthquakes (≥ 6.5) in Southern California between 1980 and 2001, as shown in Table 1.

Table 1 Y/Y_c anomalies before six strong earthquakes in Southern California during the years 1980-2001

Date	Epicenter	Magnitude/ △(km)	Max Y/Yc	Lasting Time of anomalous Y/Yc
1983.5.2	Coalinga	6.7/?	?	?
1987.11.24	Superstition Hills	6.6/0	1.4	21m
1989.10.18	Loma Prieta	7.0/100	1.2	24m
1992.6.28	Landers	7.3/100	1.0	18m
1994.1.17	Northridge	6.6/80	1.0	25m
1999.10.16	Hector Mine	7.1/100	1.4	15m

Note: Δ (km) is the distance of earthquake from the maximum Y/Y_c point.

The above results show that earthquakes occurred located near a region of anomalous Y/Y_c. Anomalous Y/Y_c is present about 1-2 years before an upcoming earthquake.

Y/Yc in periods and regions without strong earthquakes (≥ 6.5) in Southern California

Few anomalous Y/Y_c regions occurred during the periods without strong earthquakes (M ≥ 6.5). For example, no earthquakes greater than 6.5 occurred after the Hector Mine 7.1 earthquake, and there is no obvious Y/Y_c anomaly between 2000 and 2001. There may be some anomalous Y/Y_c regions without succeeding strong earthquakes, reflecting the complexity of the earthquake preparation process.

Earthquake Tendency in Southern California

Our results show that there are no obvious Y/Y_c anomalies from 2000 to 2001, which implies that there is less strong earthquake hazard in Southern California in the near future.

There are two small anomalous Y/Y_c regions in Southern California in March 2002, so there might be a moderate earthquake of about magnitude 5 around (36N, 119W) and (36N, 121.6W) within about 1 year.

Summary and Conclusions

LURR is a promising approach to mid-term earthquake prediction. However, calculation of LURR depends on high quality earthquake catalogues and other data, such as detailed knowledge of the stress field. At this time, we cannot give an exact earthquake prediction using LURR, but an approximate one.

For earthquakes greater than magnitude 6.5 in Southern California, anomalous LURR values are found in regions on the scale of 100-300km, which might imply the seismogenic region size. In addition, the evolution of anomalous LURR is complex.

Acknowledgments

This research was funded by QUAKES and NSFC(Grant 19732060, 40004002). We also show our thanks to CNSS.

References

[1] Yin, X. C., 1987, *A New Approach to Earthquake Predictio*n, Earthquake Research in China, 3,1-7(in Chinese with English abstract).

[2] Xiang-chu YIN and YIN Can, 1991, *The precursor of instability for nonlinear systems and its application to earthquake predictio*n, Science in China, **34**, 977-986.

[3] Yin, X. C., Chen, X. Z., Song, Z. P., & Yin, C. ,1995, *A new approach to earthquake prediction: the Load\Unload Response Ratio (LURR) theor*y, PAGEOPH **145**, 701-715.

[4] Yin, X.C., Wang, Y.C., Peng, K.Y., & Bai, Y.L., 2000, *Development of a new approach to earthquake prediction: Load/Unload Response Ratio (LURR) theor*y, PAGEOPH **157,** 2365-2383.

[5] X.C Yin, P. Mora, K. Peng, Y. Wang, and D. Weatherly, 2001, *Load-unload Response Ratio and Accelerating Moment/Energy Release, Critical Region Scaling and Earthquake Predictio*n, The 2 nd ACES Workshop, October 15-20, 2000, Tokyo and Hakone, Japan, Workshop abstract, pp362-368. (Submitted to PAGEOPH).

[6] Peter Mora, David Place, Yucang Wang, Xiangchu Yin, Keyin Peng and Dion Weatherley, 2000, *Earthquake forecasting: retrospective studies in Australia – the Newcastle and Burra earthquakes and numerical simulation of the physical proces*s, AEES (Australian Earthquake Engineering Society) Annual Meeting, November , 2000, Hobart, Australia.

[7] Peter Mora, David Place, Yucang Wang, Xiangchu Yin, 2000, *Simulation of Load-Unload Response Ratio in the Lattice Solid Model,* AGU (American Geophysical Union) 2000 fall Meeting, San Francisco, 10-17, December 2000.

[8] Wang, Yucang, Yin Xiang-chu and Wang Haitao (1999), *The Simulation of Rock Experiment on Load/Unload Response Ratio on Earthquake Predictio*n, Earthquake Research in China, Vol. 14, 126-130.

[9] Yu-Cang Wang, Xiang-Chu Yin, Ke-Yin Peng, 1999, *Numerical Simulation on Load/Unload Response Ratio Theor*y, Chinese Journal of Geophysics, Vol 42, No 4, 527-536.

[10] Yucang Wang, Xiang-chu Yin, Fu-jiu Ke, Meng-fen Xia, and Keyin Peng, 2000, *Numerical Simulation of Rock Failure and Earthquake Process on Mesoscopic Scal*e, Pure Appl.Geophys.,**15**7, 1905-1928.

[11] Kanamori, H., and Anderson, D.L., 1975, *Theoretical Basis of some Empirical Relation in Seismolog*y, Bull. Seismol. Soc. Am. 65, 1073-1096.

[12] Bullen, K. E., and Bolt, B.B., *An Introduction to the theory of seismolog*y (Cambridge University Press, Cambridge Press 1985).

[13] Zhuang, J. C., and Yin X. C., 1999, *Random distribution of the Load/Unload Response Ration(LURR) under Assumptions of Poisson Mode*l, Earthquake Research in China 15, 128-138.

[14] Harris, R.A., 1998, *Introduction to Special Section: Stress Triggers, Stress Shadows, and Implication for Seismic Hazar*d, J. Goephys. Res. 103, 24,347-24,358.

[15] Resernberg, P.A., and Simpson, R.W., 1992, *Response of Regional Seismicity to the Static Stress Change Produced by the Loma Preita Earthquak*e, Science 255, 1687-1690.

[16] Vidali, J.E., Agnew, D.C., Johnston, M.J.S., and Oppenheimer, D.H., 1998, *Absence of Earthquake Correlation with Earth Tides: An Indication of High Preseismic Fault Stress Rat*e, J. Geophys. Res. 103, 24,567-24,572.

[17] Zoback, M. L., 1992, *First- and second-order patterns of stress in the lithosphere: The world stress map projec*t, J. Geophys. Res., 9*7,* 11,703-11,728.