Tectonophysics 509 (2011) 191–197

Contents lists available at ScienceDirect

Tectonophysics

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

An improved version of the Load/Unload Response Ratio method for forecasting strong aftershocks

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ARTICLE INFO

Article history:
Received 10 August 2010
Received in revised form 19 May 2011
Accepted 9 June 2011
Available online 5 July 2011

Keywords:
Load/Unload Response Ratio (LURR)
Epidemic-type aftershock sequence (ETAS) model
Aftershock forecast
Wenchuan earthquake

ABSTRACT

Temporal clustering and spatial concentration of aftershock sequences can be observed after the occurrence of most major earthquakes. Earthquake clustering effects, such as the rapid decay of aftershocks and second-stage aftershocks, cause large fluctuations in the Load/Unload Response Ratio (LURR). In order to eliminate the influence of such clustering, we introduce a new formula for calculating the LURR, taking the epidemic-type aftershock sequence (ETAS) model as the baseline seismicity model. We have applied the new formula retrospectively to the Wenchuan earthquake sequence in 2008 in China. The results show that the LURR increases slowly to a peak and then decreases sharply before strong aftershocks and that the new LURR performs better than the original LURR.

1. Introduction

It is rather difficult to identify precursors to many geological disasters, such as earthquakes, landslides, and rock bursts, which in fact represent the damage–failure processes of brittle heterogeneous media. From the viewpoint of mechanics, an earthquake is essentially the failure or instability of the focal media accompanied by a rapid release of energy. Yin (1987) proposed a parameter to quantify the preparation process of a large earthquake, namely the Load/Unload Response Ratio (LURR) (Yin and Yin, 1991). The LURR is usually defined as the ratio of the total earthquake energy released during periods when the Coulomb failure stress on the earthquake fault increases and decreases due to tidal effects. Retrospective studies have been carried out for hundreds of cases using the LURR as an earthquake prediction index (Song et al., 2000; Yin et al., 1994; 1995; 1996; 2000). In addition, the LURR method has been investigated in laboratory studies, numerical simulations and from the viewpoint of fundamental physics (see Yin et al., 2002; 2004; 2006; 2008; for recent developments of the LURR method). However, the LURR method has seldom been applied to strong aftershocks, except for an attempt by Wang et al. (1998) to use it to forecast strong shocks in the Jiashi earthquake swarm.

Following a strong earthquake, it is critical to determine as soon as possible whether there will be another of similar or larger magnitude occurring within the next few days. Usually, the Omori–Utsu law or the epidemic-type aftershock sequence (ETAS) model (see Section 3 of this article) is used to describe the temporal clustering and spatial concentration of aftershock sequences and for forecasting the occurrence rate of aftershocks. However, both of these models assume only that the magnitudes of the aftershocks are identically and independently distributed random variables according to the Gutenberg–Richter law, without providing any further information about the magnitudes of coming earthquakes. The LURR can also be used to predict the occurrence of strong aftershocks. However, clustering effects and the rapid decay of aftershocks can lead to large variations in the number of aftershocks occurring in the loading and unloading periods, giving rise to strong variations in the LURR values. In order to eliminate such clustering effects, we use the ETAS model as the baseline model for evaluation of the LURR.

In this paper, we first briefly explain the concepts of the LURR and the ETAS model. We then deduce a new formula for the LURR, based on the ETAS model. This new formula is then applied to forecast strong shocks in the Wenchuan aftershock sequence in 2008 in China.

2. The Load/Unload Response Ratio

From the viewpoint of mechanics, the essence of an earthquake is a failure or instability of the focal media accompanied by a rapid release of energy. Therefore, the preparation process of an earthquake is exactly the damaging process of the focal media. On a microscopic scale, damage mechanisms in geomaterials (rocks) are incredibly

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0040-1951/$ – see front matter © 2011 Published by Elsevier B.V.
doi:10.1016/j.tecto.2011.06.008