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Migration trend of strong earthquakes in North China from numerical simulations

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ABSTRACT

Lu et al. (2011) established a finite element model around the entire Chinese continent to simulate the distant migration of strong earthquakes by killing the elements. In this study a new finite element model of North China has been established in the existing Chinese continental model using the GPS observations and the finite element sub-model technique through taking into account geological structure, active faults, surface topography, Moho discontinuity and 3-D velocity structure of the crust and upper mantle in the region. Furthermore, the stress field adjustment was realized by reducing the element stiffness rather than by killing the elements. We calculated the displacement of the Chinese continent model, and took the displacement located at the boundary of North China as the boundary loadings, then computed the initial stress field by considering the gravity effect. The migration of the strong earthquake regions was simulated by performing a number of tests with various kinds of short-term boundary loadings. Locations of strong earthquakes were determined with the highest *G* (the risk factor of the fault) value and adjustment of the stress field. Our results showed that high stress disturbance regions could be possible regions of future strong earthquakes, and that the initial stress field in North China can be well estimated, if an optimal boundary loading configuration is chosen in the Chinese continental model. These results suggest that the strong earthquake forecast in North China may strongly depend on the stress field and strong earthquake activities in a much wider area, such as the Chinese continent.

1. Introduction

Through analyzing earthquake activities and precursory phenomena, including crustal stress and strain, geomagnetical, geoelectrical anomalies, and ground fluids, a few moderate-strong earthquakes were once successfully predicted and natural hazards were mitigated significantly (Ding et al., 2000). However, the failure of the prediction to some destructive earthquakes, such as the 1976 Tangshan (*M* 7.8) and 2008 Wenchuan (*M* 8.0), China, earthquakes, renders us to ponder the feasibility of earthquake prediction and related scientific investigations. A common consensus is that due to the complexity and nonlinearity of seismogenic structures, it is extremely hard to obtain useful information on the earthquake pregnancy and occurrence, and nowadays more difficult to predict the exact location, magnitude, and origin time. It is almost impossible to achieve a significant breakthrough in the earthquake prediction if we only depend on precursor observations.

One wants to know whether there exists a possibility to predict the trend of strong earthquakes based on the deficient understanding of crustal structure, the property of fault zones, and crustal movements. Wang et al. (1982) once simulated strong earthquakes ($M \geqslant 7.0$) over the past 700 years, and found that most earthquakes occurred around the region with an increased value of the risk factor $G = \tau/(\sigma_n \tan\phi)$, where τ is the shear stress along the fault plane, σ_n is the normal stress on the fault plane, and ϕ is the friction angle. Zhang et al. (1990) jointly inverted the 1966 Xingtai (*M* 7.2), 1969 Bohai (*M* 7.4), 1975 Haicheng (*M* 7.3), 1976 Tangshan (*M* 7.8), China, earthquakes, and found that the occurrence of strong earthquakes could be resulted from the activity and extension of the fault system. Tao et al. (2000) established a viscoelastic finite element model in the Chinese continent, and obtained the distribution of strain and stress field. Chen et al. (2001) investigated a dynamic evolution process of the 1966 Xingtai earthquake, and concluded that the occurrence of the 1966 Xingtai earthquake could play a key role in the stress variation around the 1978 Tangshan source area. Bai et al. (2003) simulated the dynamic process of the Tangshan earthquake, and found that the earthquake significantly affected its adjacent blocks and border faults and led to various sizes of ground movement and surface deformation around it. Based on these studies, Lu (2004) proposed a seismic dynamic prediction model attributable to a remarkable process in the computer technique, geodynamics, deep seismic structure, GPS observations, and continental deep drillings. In the seismic dynamic prediction model, we do not only take into account one or several faults and the interaction between the block and its surrounding fault system, but also dynamic processes of stress concentration and fault slipping in the brittle and

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brittle-ductile mid-upper crust away from the plate boundaries. Assuming a sudden weakening of a localized weak lower crust embedded in an elastic crust, Kenner and Segall (2000) concluded that weakening in the lower crust can causes stress amplification in the upper crust and result in a sequence of ruptures of the fault zone. Li et al. (2009) investigated different cases of fault weakening after a large fault rupture, and concluded that fault weakening can lead to repeated earthquakes. Lu et al. (2011) made an attempt to establish a finite element model of the entire Chinese continent (Fig. 1a) by killing the elements (no loading capability) after the earthquake, but this method cannot predict where the next earthquake occurs. However, the purpose of the dynamic prediction at the current stage is to forecast the migration trend of an incoming strong earthquake region so as to provide an important scientific evidence for capturing the seismic precursors to mitigate the seismic hazard.

Recently, in North China many investigations have being conducted using various approaches, such as seismic tomography (Lei et al., 2008, 2011; Huang et al., 2009), active faults (Deng et al., 2002), and GPS observations (Jiang et al., 2000), and obtained many significant results. These results allow us to model the migration trend of the strong earthquake region in North China by introducing these previous results into our model. To achieve practical and meaningful forecast of strong earthquakes with the purpose of the mitigation of seismic hazard, the region of the predicted earthquakes should not be too large. Therefore, in the present study we took North China as an example to explore the migration trend of follow-up strong earthquakes. Because the loading configuration could not be changed significantly within an active period of about 10 years, the migration of strong earthquakes could be mainly controlled by the source areas without load-bearing capacity and induced stress adjustment. Our simulation steps

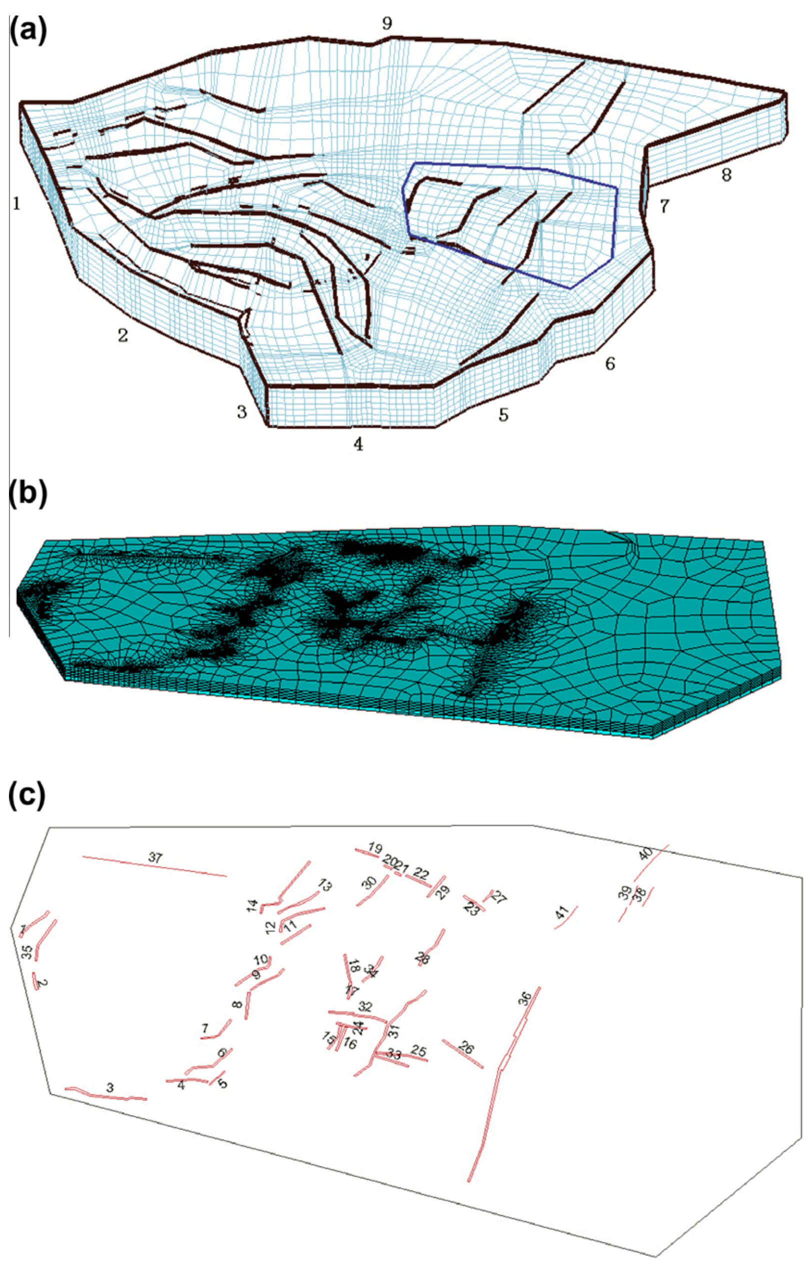

Fig. 1. (a) Location of the North China sub-model (open polygon) in the entire Chinese continent finite element model of Lu et al. (2011). Black lines denote major active faults in China, while other lines denote the model parameterization. The digital numbers denote the model boundary. (b) A finite element model of North China. (c) Distribution of the faults used in the finite element model of North China. The numbers denote the faults as shown Table 1.