Geodesy and Geodynamics 8 (2017) 84–89

Contents lists available at ScienceDirect

Geodesy and Geodynamics

journal homepages: www.keaipublishing.com/en/journals/geog; http://www.jgg09.com/jweb_ddcl_en/EN/volumn/home.shtml

Extrusion deformation process of ground surface during the Lushan earthquake in China

Yuzhu Bai

Key Laboratory of Active Tectonics and Volcano, Institute of Geology, China Earthquake Administration, Beijing, China

ARTICLE INFO

Article history:
Received 2 July 2016
Accepted 18 January 2017
Available online 3 February 2017

Keywords:
Lushan earthquake
Extrusion deformation
Finite element method

ABSTRACT

Based on finite element method, the extrusion deformation process of ground surface during the Lushan earthquake (April 20, 2013) is investigated in this work. In order to construct the finite element model of Lushan earthquake structure, the geophysical layer model of Lushan area, the frictional characteristic of slip-weaken along the fault surface, and the Coulomb failure criterion are considered. Through the computation and the comparison with achievement on the Lushan focal dynamics, our researches indicate that: (1) The most extrusion deformation of ground surface occurred in the initial phase of earthquake procession, i.e., between the fourth and sixth seconds after the earthquake occurred. (2) Between the first and sixth seconds after the earthquake, the extrusion deformation concentrates on the surface projection of earthquake fault. (3) Between the first and third seconds after the earthquake, the extrusion deformation of ground surface is very tiny. Meanwhile, the extrusion deformation reaches maximum at the sixth second after earthquake. (4) After 6 s of Lushan earthquake, the extrusion deformation spread out of earthquake structure projection. (5) During the earthquake, the maximum of extrusion deformation on ground surface is larger than the final deformation of the post-earthquake, in other words, the ground extrusion deformation will lastly reach a relatively small value after the Lushan earthquake occurred.

1. Introduction

Lushan earthquake, occurred on 20 April 2013 in Sichuan Province, China, is another destructive earthquake five years after the 2008 Wenchuan earthquake. Besides the disasters made by these two earthquakes, the main difference of these two events is the earthquake structure and the ground surface deformation. As we know now that Wenchuan earthquake is made by surface break fault and has large co-seismic surface rupture zone [1]. While, Lushan earthquake is caused by the blind-reverse fault with depth of top boundary of fault about 9 km and has no visible co-seismic surface ruptures [1]. So the above facts prove that the different deformation of ground surface is related to the earthquake structure and its rupture motion. Alternatively, in a point view of seismic source physics, the process of both rupture motion of fault and ground surface deformation is correlated.

After Lushan earthquake, there are a lot of researches on the kinematic slip process [1–4] of Lushan focus through the inversion of seismic data. As the most researches indicate, the kinematic slip process of Lushan focus is divided into two phases. At the first phase of slip motion of focus, the earthquake fault ruptures in all around the nuclear point. Then, in the second phase, the earthquake fault ruptures from the southwest to northeast. Similarly, there are many research achievements [5] on the co- and post-seismic deformation on the ground surface for Lushan earthquake. However, there is few report on the deformation processes of ground surface for Lushan earthquake now.

In this work, the finite element method is applied to investigate the extrusion deformation process of ground surface during Lushan earthquake. During the construction of the finite element model of Lushan earthquake structure, the geophysical layer model of

E-mail address: yuzhubai2008@126.com.

Peer review under responsibility of Institute of Seismology, China Earthquake Administration.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.geog.2017.01.007

Lushan area, the frictional characteristic of slip-weaken along the fault surface, and the Coulomb failure criterion are considered.

2. Lushan earthquake fault and model parameters

The epicentre of Lushan earthquake and the earthquake faults are shown in Fig. 1. The Lushan earthquake occurred in the southern section of the Longmenshan Mountain Fault zone (LFZ), which is the boundary between the Bayan Har Block in the Tibetan Plateau and the South China block to the east [6]. In the southern section of the LFZ, there are many secondary thrust faults. Several NE-trending faults, shown in Fig. 1, Gengda-Longdong (F1) Yanjing-Wulong (F2) and Shuangshi-Dachuan (F3), parallel from west to east [7]. The Yanjing-Wulong Fault (F2 in Fig. 1) is in the southern section of the Longmenshan Mountain central fault zone. The Genda-Longdong (F1 in Fig. 1) Fault is in the southern part of Longmenshan Mountain–Houshan Mountain, and it is the northwest boundary fault of the Longmenshan Mountain Fault zone. The Shuangshi-Dachuan Fault (F3 in Fig. 1) is in the southern part of Longmenshan Mountain–Qianshan Mountain Fault zone, and it is the southeastern boundary fault of the Longmenshan Mountain Fault zone. The focus of Lushan earthquake is located on the Shuangshi-Dachuan Fault (F3). The Lushan earthquake fault geometry scale and the bury depth will be set according to the result of Xu et al. [1] and Wang et al. [4]. In the achievements of Wang et al. [4], the Lushan earthquake fault is set as 66 km in the strike and 30 km in the dip direction. According to the scientific survey and aftershock relocation, Xu [1] indicated the depth to the top of Lushan earthquake rupture is 9 km, as shown in Fig. 2. In fact, although there are many researches on the Lushan earthquake fault parameters based on the different inversion methods, the results do not differ much. Finally the Lushan earthquake fault parameters are listed in Table 1. In order to account for the layer geophysic features of Longmenshan Mountain area, we will apply the geophysical layer model [8] which parameters are shown in Table 2. Since in the work of Shan et al. [8], the computation region cover the area of present research, the parameters of layer crustal model of reference [8] applied here should be reasonable.

Just as shown in Figs. 1–3, the finite element model corresponding to the Lushan earthquake fault is constructed. The dimensions of model in direction of normal to and along the fault

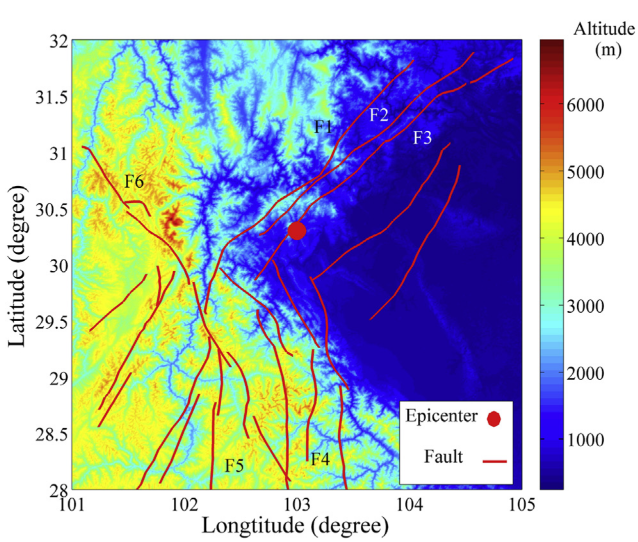

Fig. 1. Faults and the epicentre of Lushan event. (F1-Gengda-Longdong Fault; F2-Yanjing-Wulong Fault; F3-Shuangshi-Dachuan Fault; F4-Yingjing Fault; F5-Anninghe Fault;F6-Xianshuihe Fault.)

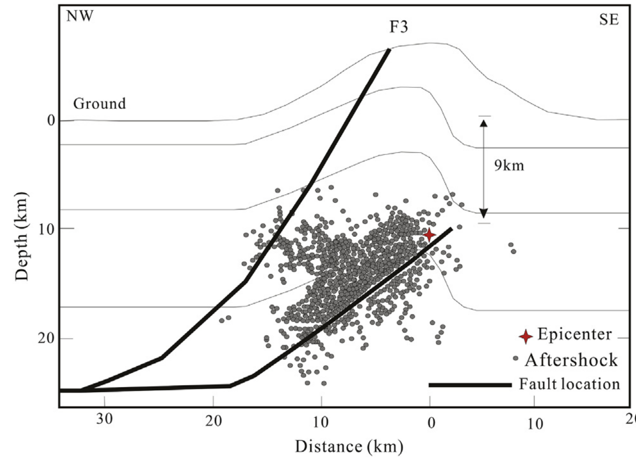

Fig. 2. Seismogenic structure and distribution of aftershocks.

strike, and depth direction are 100 km, 100 km, and 42 km respectively. There are about 560,000 six-node pentahedral elements applied to fill the whole model space. The scale of the element is 1000 m × 1000 m × 750 m. The time step in the computation is set to 0.05 s. On the fault surface, the frictional relation is applied to the slip-weaken relations [9,10], as shown in Eq. (1), the frictional coefficient f decreases linearly as a function of slip from the static frictional coefficient f_s to the dynamic frictional coefficient f_d over a critical slip-weakening distance D_c (Fig. 4).

$$f = \begin{cases} f_s & D'(t) = 0 \\ f_s - (f_s - f_d)\dfrac{D(t)}{D_c} & D(t) \le D_c \\ f_d & D(t) > D_c \end{cases} \quad (1)$$

The coefficient of dynamic friction is chosen to be constant, $f_d = 0.62$ and the static friction is $f_s = 0.65$. These values are consistent with laboratory friction experiments at small slip [11,12]. At the same time, the D_c is set to be 0.4 m [13]. The failure of fault surface is applied the Coulomb criterion [13] and the cohesive force is set 6 MPa [12]. After setting the model parameters, the computation is carried on the IBM sever of System ×3400 M3 which has 72G internal memory and two Intel(R) Xeon R-E5620 CPUs. It will take the IBM sever almost 30–35 h to carry one simulation experiment.

3. Computation results

Fig. 3 is the snapshot of extrusion deformation process for the ground surface during the Lushan earthquake. In Fig. 3, the deformation units are metres and the units of horizontal and vertical coordinates are kilometres. According to the kinematic inversion of Lushan earthquake focus, the duration of fault rupture approximates 8 s [3]. Therefore, the deformation of ground surface in the 8 s after the Lushan earthquake is shown for every second in Fig. 3. When time is larger than 8 s, since the rupture motion stopped, some selected snapshot of ground extrusion deformation are also shown in Fig. 3. Through the strong ground motion record in Lushan earthquake [14], the duration time of ground shaking is about 60 s. So, in Fig. 3, the ground extrusion deformation at 60th second after earthquake happening is shown. In addition, the positive value of deformation in Fig. 3 means that the extrusion deformation along the direction normal to the fault strike from the top left to bottom right. The minus value of deformation