Journal of Asian Earth Sciences 50 (2012) 164–170

Contents lists available at SciVerse ScienceDirect

Journal of Asian Earth Sciences

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

Coseismic horizontal shortening associated with the 2008 Wenchuan Earthquake along the Baishahe segment from high resolution satellite images

Feng Shi, Hong-Lin He *, Zhan-Yu Wei

Key Laboratory of Active Tectonics and Volcano, Institute of Geology, China Earthquake Administration, Beijing 100029, China

ARTICLE INFO

Article history:
Received 12 May 2010
Received in revised form 11 January 2012
Accepted 17 January 2012
Available online 22 February 2012

Keywords:
Wenchuan Earthquake
Coseismic horizontal shortening
Image contrast

ABSTRACT

Many coseismic deformation data from the Wenchuan Earthquake of 12 May, 2008, have been published; however, most of the data record strike-slip and vertical offsets, and there is little information on the horizontal shortening components. To determine the amount of horizontal shortening, we suggest a new method of measuring the differences in the positions of geometrical markers observed in satellite images before and after the earthquake. We found two roads that run nearly parallel to the earthquake rupture but on opposite sides, and we examined the spacing between them before and after the earthquake. We were able to measure horizontal shortenings that average 6.6 ± 1.84 m, with a maximum of 11.0 m and a minimum of 1.1 m. As an alternative method, we used a GPS RTK field survey system to measure the spacing of the two roads after the earthquake, and then measured the difference between that and the spacing determined from satellite images before the earthquake. This method gave horizontal shortenings that average 7.1 ± 1.3 m, with a maximum of 9.85 m and a minimum of 3.8 m. The shortenings measured, using either of these two methods, are larger than those directly measured in the field in the immediate vicinity of the fault, which suggests that the coseismic horizontal shortening is distributed over a wider area that extends some distance away from the brittle fault scarp itself. Finally, the results support a low-angle fault model for the Wenchuan Earthquake, and they provide useful insights into the seismotectonics of eastern Tibet, especially the building of the Longmenshan range.

1. Introduction

The Ms 8.0 Wenchuan Earthquake, which struck Sichuan, China, on 12 May 2008, was accompanied by the rupture of two NW-dipping imbricate reverse faults along the Longmenshan fault zone at the eastern margin of the Tibetan Plateau (Burchfiel et al., 2008; Liu-Zeng et al., 2009; Xu et al., 2009). Seismological studies indicate that the main shock was initiated approximately 20 km southwest of the town of Yingxiu, with the rupture propagating northeastwards for about 300 km at an average speed of 2.8 km/s, and for a period of 110–120 s (Nakamura et al., 2010; Wang et al., 2008, 2009). Field investigations show that the earthquake generated a major rupture about 250 km in length along the Beichuan–Yingxiu Fault, as well as a minor rupture about 72 km in length along the parallel Guanxian–Jiangyou Fault (Li et al., 2010; Liu-Zeng et al., 2009; Xu et al., 2009). The observed co-seismic slips show that faulting on the major rupture zone (the Beichuan–Yingxiu Fault) consisted of upwards thrusting of the northwest hanging wall, together with some component of right-lateral strike-slip. On the minor rupture zone, the Guanxian–Jiangyou Fault, only reverse slip is observed (Liu-Zeng et al., 2009; Xu et al., 2009). Along the Beichuan–Yingxiu Fault, the observed maximum vertical displacements are ∼9.5 m (Ran et al., 2010) or ∼6.5 m (Xu et al., 2010), and the strike slip displacements are ∼4.8 m (He et al., 2008) or ∼4.9 m (Xu et al., 2009). On the Guanxian–Jiangyou Fault, the observed maximum vertical displacement is ∼3.5 m (Liu-Zeng et al., 2009; Xu et al., 2009).

Most of the coseismic slip data, collected in the field (e.g., He et al., 2008; Liu-Zeng et al., 2009; Xu et al., 2009), record strike-slip and vertical offsets. The amount of horizontal shortening, which is as important as the strike-slip and vertical offsets, has seldom been measured (Chen et al., 2008, 2009; He et al., 2008; Shi et al., 2009; Wang et al., 2010). The coseismic slip vector has strike slip, vertical slip, and horizontal shortening (or extension) as its three components in space, and a reasonable and reliable estimate of all three components is essential if we are to understand the coseismic surface deformation. Although GPS and InSAR data have provided information on the coseismic displacement field of the Wenchuan Earthquake (Hao et al., 2009; Hashimoto et al., 2010; The Project of Crustal Movement Observation Network of China, 2008), the InSAR data often fail near the fault due to excessive temporal decorrelation of the images and signal saturation (Klinger et al., 2006). Furthermore, SAR data only provide the satellite to ground component

* Corresponding author. Address: 19 Beituchengxilu Road, Beijing 100029, China. Tel./fax: +86 10 62009215.

E-mail addresses: skywazy@126.com (F. Shi), honglinhe123@vip.sina.com (H.-L. He), weizhanyu@gmail.com (Z.-Y. Wei).

1367-9120/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jseaes.2012.01.001

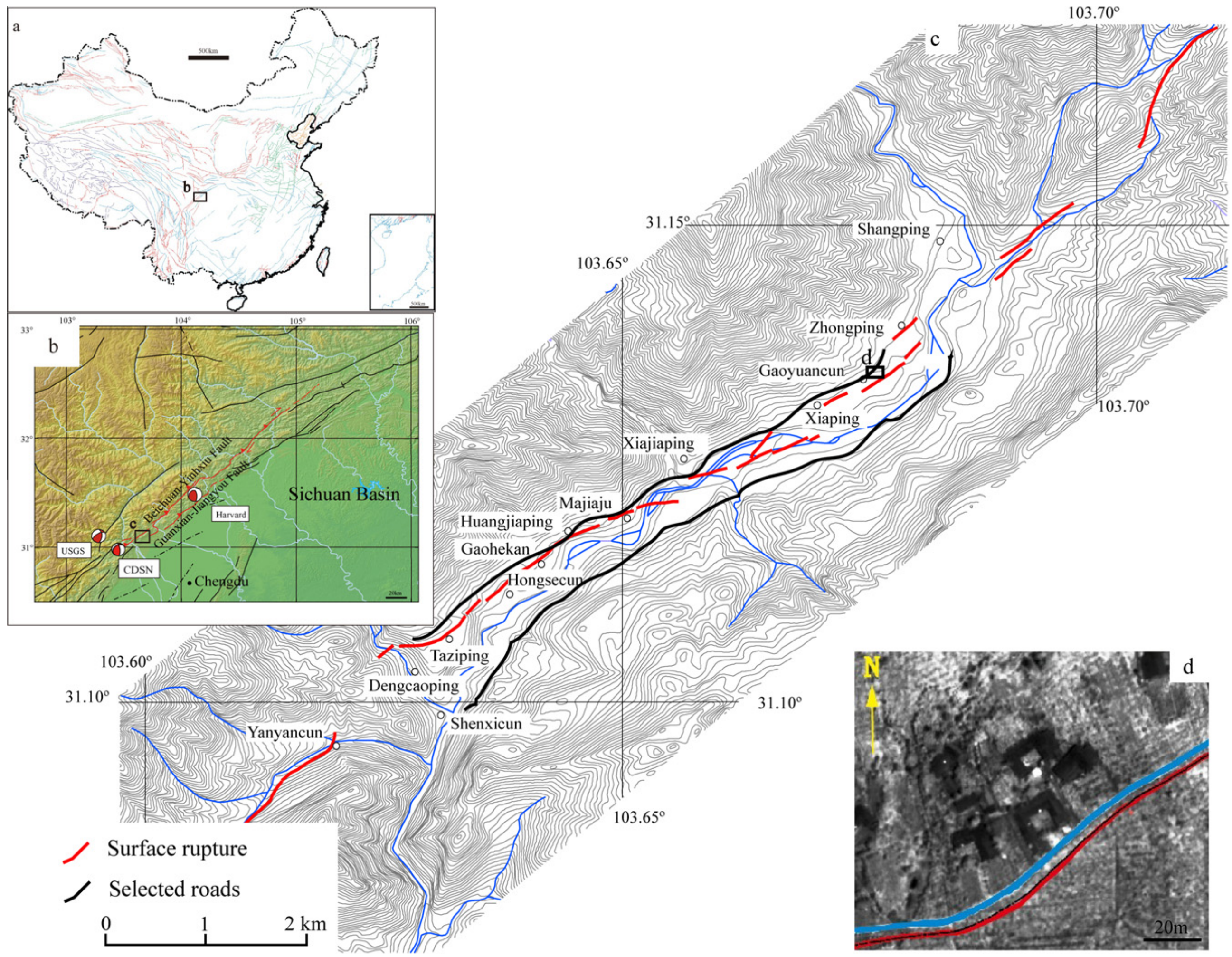

Fig. 1. Surface ruptures in the Baishahe segment and locations of the reference roads. (a) Active tectonics in China (Deng, 2007); the black rectangle shows the location of (b). (b) Surface rupture formed during the Wenchuan Earthquake shown by red lines (Xu et al., 2009); black lines show other active faults; black rectangle shows the location of (c). (c) Surface ruptures in the Baishahe segment (from He et al. (2008)) and selected roads; black rectangle shows the location of (d). (d) Local roads on QuickBird images pre-earthquake (blue zone) and post-earthquake (red zone), and the eastern roadside measured in the field (black dotted line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of the deformation (Michel and Avouac, 2002). Because there are only a few stations immediately adjacent to the fault, the GPS data only show the deformation field at some distance from the fault (The Project of Crustal Movement Observation Network of China, 2008). The recently developed sub-pixel correlation method provides new information on co-seismic displacements, and it has now been applied to several earthquakes (Dominguez et al., 2003; Klinger et al., 2006; Michel and Avouac, 2002; Pumbroeck et al., 2000). The method is limited mainly by the decorrelation of the images, the accuracy of the digital elevation model (DEM), the aliasing of the images, and the uncertainties concerning the measured roll, pitch, and yaw of the satellite (Pumbroeck et al., 2000). To avoid the error due to the contrast of two optical satellite images, we provide here a new and simpler method of measuring the coseismic shortening by subtracting differences in the positions of geometrical markers observed in satellite images before and after the earthquake.

In this paper, the rupture along the Baishahe River is used as a case study to calculate the coseismic shortenings. This rupture is located to the southwest of the major rupture, it extends 14 km along the Baishahe River, and is approximately 15 km northeast of the epicenter of the Wenchuan Earthquake. Its geometry is complicated, with many short sections striking 50° on average and dipping northwest. The maximum vertical and strike-slip coseismic offsets, measured along the Baishahe River rupture (He et al., 2008), are 6.5 m and 4.8 m, respectively. There are two roads that run nearly parallel to most of the rupture (Fig. 1), one to the northwest of the rupture, the other to the southeast. They provide excellent markers for measuring the horizontal shortening. On satellite images we can measure the distance between the two roads normal to the average strike of the rupture, and observe the changes before and after the Wenchuan Earthquake. These observations can then be used to calculate the coseismic horizontal shortening.

2. Methods and data

QuickBird satellite images were used for this study because of their high resolution (0.6 m), arguably the best among the commercial satellite images presently available. The two roads run parallel to the Baishahe River rupture, but on opposite sides, and they are used as geometric markers. The procedures were as follows:

Firstly, a field survey was made of the two selected roads using a GPS RTK measuring system. Road segments that were apparently repaired or reconstructed after the earthquake were not included in the survey.