ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xxx (2018) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Crustal deformation characteristics of Sichuan-Yunnan region in China on the constraint of multi-periods of GPS velocity fields

Caiya Yue [a,b], Yamin Dang [b,c,*], Huayang Dai [a], Qiang Yang [b], Xiankai Wang [a]

[a] College of Geoscience and Surveying Engineering, China University of Mining & Technology, Beijing, Beijing 100083, China
[b] Chinese Academy of Surveying and Mapping, Beijing 100830, China
[c] College of Geomatics, Shandong University of Science and Technology, Qingdao, Shangdong 266590, China

Received 21 September 2017; received in revised form 24 January 2018; accepted 28 January 2018

Abstract

In order to obtain deformation parameters in each block of Sichuan-Yunnan Region (SYG) in China by stages and establish a dynamic model about the variation of the strain rate fields and the surface expansion in this area, we taken the Global Positioning System (GPS) sites velocity in the region as constrained condition and taken advantage of the block strain calculation model based on spherical surface. We also analyzed the deformation of the active blocks in the whole SYG before and after the Wenchuan earthquake, and analyzed the deformation of active blocks near the epicenter of the Wenchuan earthquake in detail. The results show that, (1) Under the effects of the carving from India plate and the crimping from the potential energy of Tibetan Plateau for a long time, there is a certain periodicity in crustal deformation in SYG. And the period change and the earthquake occurrence have a good agreement. (2) The differences in GPS velocity fields relative Eurasian reference frame shows that the Wenchuan earthquake and the Ya'an earthquake mainly affect the crustal movement in the central and southern part of SYG, and the average velocity difference is about 4–8 mm/a for the Wenchuan earthquake and 2–4 mm/a for the Ya'an earthquake. (3) For the Wenchuan earthquake, the average strain changed from 10 to 20 nanostrian/a before earthquake to 40–50 nanostrian/a after the earthquake, but before and after the Ya'an earthquake, the strain value increased from about 15 nanostrian/a to about 30 nanostrian/a. (4) The Wenchuan earthquake has changed the strain parameter of each active block more or less. Especially, the Longmen block and Chengdu block near the epicenter. The research provides fundamental material for the study of the dynamic mechanism of the push extrusion from the north-east of the India plate and the crimp from Qinghai Tibet Plateau, and it also provides support for the study of crustal stress variation and earthquake prediction in Sichuan Yunnan region.

Keywords: Sichuan-Yunnan region in China; Deformation parameter; Wenchuan earthquake; Active block

1. Introduction

The SYR is located in the Southwest of China, mainly including Sichuan Province, Yunnan province and the small parts of the provinces that are adjacent to the two provinces. This area is situated the Himalaya Range - Mediterranean seismic belt, and has long been a push extrusion from the North-east of the India plate and a crimp from Qinghai Tibet Plateau, as well as the blocking effect from stable block of Southern China. All these made the whole area rotate clockwise, the tectonic deformation activity has been violent and the strong earthquakes occur frequently (Yue et al., 2017; Thatcher, 2007; Meade and Hager, 2005; Shen et al., 2005a,b). Therefore, in recent years, this area had become an ideal place for Geosciences researchers to study the hot issues such as the formation

* Corresponding author at: Chinese Academy of Surveying and Mapping, Beijing 100830, China.
E-mail address: ycycasm@student.cumtb.edu.cn (C. Yue).

https://doi.org/10.1016/j.asr.2018.01.039

Please cite this article in press as: Yue, C., et al. Crustal deformation characteristics of Sichuan-Yunnan region in China on the constraint of multi-periods of GPS velocity fields. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2018.01.039

and evolution mechanism of the Qinghai Tibet Plateau, the crustal deformation model, seismic incubation and migration patterns, etc. (Fielding et al., 2013; Feng et al., 2010; Wang et al., 2011a,b; Wen et al., 2013).

With the increased of precision of GPS observation model and data resolution software, the application of GPS in geodynamics is becoming more and more widespread. After statistics, the GPS single day positioning accuracy is less than 3 mm in the horizontal direction and 6 mm in the vertical direction by using the optimal model. And the horizontal and vertical accuracy can be about 1 mm and 3 mm respectively under the observation data solution with long time scale. Therefore, it can be retrieved the present activity rate of each block and fault zone in SYG based on the GPS horizontal velocity fields and the dense GPS stations layout (Guo et al., 2013). Besides, it can be concluded that the variation of maximum principal compressive stress and the maximum shear stress are in good agreement with the seismicity during the same period and region (Zhang et al., 2010).

For the SYG, many scholars have carried out a great deal of researches based on the geological structure environment and observation methods (such as GNSS velocity, InSAR and gravity measurement, etc.). Shen et al. (2005a, b) revealed that the crust was fragmented into tectonic blocks of various sizes, separated by strike-slip and transtensional faults by using GPS data; Zhang et al. (2008,2009) calculated the slip rate of the fault zone before the Wenchuan earthquake and put forward a multi-unit combinatorial model based on GPS data, geomorphologic rupture and dating. Luo and Liu (2010) shown that the cumulative Coulomb stress changes were significantly different when previous large earthquakes in the region, but which hence the implied earthquake risks. (Zou et al., 2015) shown that Wenchuan earthquake has a large impact for adjustment range, and the influence was gradually reduced after the earthquake by multi-phase GPS velocity fields. In addition, SYG is an important part of the North – South seismic belt, and its tectonic deformation have a close relationship with this area. So many researches have been done for the NS seismic belt (Clark and Royden, 2000; Chen et al., 2001; Densmore et al., 2007; Hubbard and Show, 2009; Zhang et al., 2010; Zhang, 2013).

In this paper, based on the high precision calculation of GPS observation data from 1999 to 2016 in SYG, the velocity field information and the spherical coordinate are obtained. And obtained strain rate fields and crustal dilatation in various phases and strain rate fields and crustal dilatation before and after the Wenchuan earthquake with used the velocity field information and spherical coordinate model. By analyzing the deformation parameters of the region, it was concluded that the extent of compressional and tensile deformation of the crust in the SYG is periodically changed. In these changes, however, earthquakes played a role of redistribution of crustal stress. In other words, a certain degree of regulative function.

2. Block strain rate fields model

GPS velocity field information can directly reflect the obvious structural difference movement characteristics in the study area, but it can't reflect some fine deformation characteristics effectively, and the strain rate fields can reflect the internal deformation of blocks visually and finely.

When calculate the strain rate fields of a block, the crust can be divided into plane and spherical according to the size of the region. Since the SYG spans 14 degrees from North to South and 13 degrees from east to west, the region of the study is large, so the spherical coordinate is used when calculating the block deformation parameter (Shi and Zhu, 2006; Xu and Wen, 2003; Ding et al., 2013). A formula for calculating strain in a spherical coordinate system:

$$\left.\begin{aligned}
&\varepsilon_\theta = \frac{1}{r}\frac{\partial u_\theta}{\partial \theta} + \frac{u_r}{r}\\
&\varepsilon_\varphi = \frac{1}{r\sin\theta}\frac{\partial u_\varphi}{\partial \varphi} + \frac{u_\theta}{r}\cot\theta\\
&\varepsilon_r = \frac{\partial u_r}{\partial r}\\
&\varepsilon_{\theta\varphi} = \frac{1}{2}\left[\frac{1}{r\sin\theta}\frac{\partial u_\varphi}{\partial \varphi} - \frac{u_\varphi}{r}\cot\theta + \frac{1}{r}\frac{\partial u_\varphi}{\partial \theta}\right]\\
&\varepsilon_{r\theta} = \frac{1}{2}\left[\frac{1}{r}\frac{\partial u_r}{\partial \theta} - \frac{u_\varphi}{r} + \frac{\partial u_\theta}{\partial r}\right]\\
&\varepsilon_{r\varphi} = \frac{1}{2}\left[\frac{\partial u_\varphi}{\partial r} + \frac{1}{r\sin\theta}\frac{\partial u_r}{\partial \varphi} - \frac{u_\varphi}{r}\right]
\end{aligned}\right\} \quad (1)$$

where θ, φ and r are the colatitude, east longitude and the radius of the Earth. u_φ, u_θ and u_r are the east-west deformation, South-North deformation and vertical deformation. ε_θ, ε_φ and ε_r are the principal strain in three directions; $\varepsilon_{\theta\varphi}$, $\varepsilon_{r\theta}$ and $\varepsilon_{r\varphi}$ are the shear strain in three directions. In the process of GPS data calculation, we can obtain three-dimensional velocity information and high-precision coordinate of stations finally.

Based on the Taylor expansion at the center of the block and combined coordinates and velocities of GPS sites can obtain the Eq. (2) of block deformation. In the actual calculation process, used the Eq. (1) in Eq. (2) and replaced the u_φ, $-u_\theta$, U_φ, $-U_\theta$, $\Delta\varphi$, $-\Delta\theta$ with v_e v_n V_e V_n ΔL ΔB respectively (Xu and Wen, 2003). Eq. (3) of strain parameter can be obtained by the least square method.

$$\left.\begin{aligned}
&u_\theta = U_\theta + \frac{\partial u_\theta}{\partial \varphi}\Big|_0 \Delta\varphi + \frac{\partial u_\theta}{\partial \theta}\big|_0 \Delta\theta + r_0\frac{\partial u_\theta}{\partial r}\big|_0 \frac{\Delta r}{r_0} + \Delta_\theta^n\\
&u_\varphi = U_\varphi + \frac{\partial u_\varphi}{\partial \varphi}\big|_0 \Delta\varphi + \frac{\partial u_\varphi}{\partial \theta}\big|_0 \Delta\theta + r_0\frac{\partial u_\varphi}{\partial r}\big|_0 \frac{\Delta r}{r_0} + \Delta_\varphi^n\\
&u_r = U_r + \frac{\partial u_r}{\partial \varphi}\big|_0 \Delta\varphi + \frac{\partial u_r}{\partial \theta}\big|_0 \Delta\theta + r_0\frac{\partial u_r}{\partial r}\big|_0 \frac{\Delta r}{r_0} + \Delta_r^n
\end{aligned}\right\} \quad (2)$$

It is usual to expand u_φ, u_θ and u_r according to Taylor formula based on the block center, and used the coordinate information and three-dimensional velocity information of stations. Based on these, we can obtain the block deformation expansion formula (2) and the solution of strain parameters based on the least square principle (3).