Discussion on ‘Was the 2008 Wenchuan earthquake triggered by Zipingpu Reservoir?’*

Shiyong Zhou^{1,†} Kai Deng¹ Cuiping Zhao² Wanzheng Cheng³

¹ School of Earth and Space Sciences, Peking University, Beijing 100871, China

² Institute of Earthquake Science, China Earthquake Administration, Beijing 100036, China

³ Earthquake Administration of Sichuan Province, Chengdu 610041, China

Abstract Some recent publications presented a result suggesting that Zipingpu reservoir hastened the occurrence of the 2008 $M_s8.0$ Wenchuan earthquake by tens to hundreds of years. Their researches calculated the Coulomb stress change induced by Zipingpu reservoir on the rupturing fault of Wenchuan earthquake. Their results, however, are critically dependent upon the 3-D event location, reservoir location, and the fault plane orientation. We repeated Ge et al.’s work in this paper and found that an improper dip angle parameter of their 2-D fault model might lead to a wrong conclusion. Both the modeling results based on the 2-D model and 3-D model with proper fault parameters will show Coulomb stress changes alone were neither large enough nor had the correct orientation to affect the occurrence of Wenchuan earthquake, which supports our recent argument based on the local seismicity analysis and the induced Coulomb stress change calculation with a 3-D model.

Key words: Wenchuan earthquake; reservoir induced seismicity; Coulomb stress

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1 Introduction

Whether the disastrous 2008 Wenchuan $M_s8.0$ earthquake was or was not triggered by the reservoir behind the Zipingpu Dam is still under discussion (Kerr and Stone, 2009, 2010; Chen, 2009b; Ge et al., 2009), as emphasized in the recent article by Kerr and Stone (2010). The Science news story makes the main news point proposed by Chen (2009a), which is obviously opposite to the article by Ge et al. (2009). Among all published discussions, Lei et al. (2008) and Ge et al. (2009) might have a very strong impact on both the scientific community and the society of China. Both these papers presented a result suggesting that the Zipingpu reservoir hastened the occurrence of the Wenchuan earthquake by tens to hundreds of years. Their researches calculated the Coulomb stress change induced by Zipingpu reservoir on the rupturing fault of the Wenchuan earthquake. Their results, however, are critically dependent upon the hypocenter location, the res-

ervoir location, and the fault plane orientation. We have done similar work and infer that Coulomb stress changes alone were neither large enough nor of the correct sign to promote this disastrous earthquake.

2 Discussion

Recent studies show that the Wenchuan earthquake location has changed little from the initial location determined by China Earthquake Administration, despite the early analysis of Bergman and Engdahl (2008). Most of relocation results show that the focal depth of Wenchuan earthquake ranges within 14–19 km (Huang et al., 2008; Zhu et al., 2008; Wang et al., 2008; Chen et al., 2009; Zhang et al., 2009) and the epicenter is around (31.0°N, 103.4°E). Additionally, several focal mechanism solutions and moment tensor inversions show that the fault plane dip was approximately 35° with a 229° strike (Chen et al., 2008; Ji et al., 2008; Wang et al., 2008; Zhang et al., 2009). We have used these results to make 3-D estimates of the Coulomb stress change on the event fault plane.

Ge et al. (2009) put the reservoir on the foot-wall side of this rupturing fault to calculate Coulomb stress variation induced by the reservoir in their 2-D model. It

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† Corresponding author. e-mail: zsy@pku.edu.cn

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can be inferred from Ge et al. (2009)'s paper that the dip angle around the focal region is about 45° , which is obviously larger than 35° reported by Harvard and 32° reported by USGS (http://neic.usgs.gov/neis/eq_depot/2008/eq_080512_ryan/neic_ryan_hrv.html; <http://www.globalcmt.org/CMTsearch.html>). In Figure 2b we use the dip with 35° and keep the others the same to repeat Ge et al.'s (2009) calculation, and find that the Coulomb stress change is negative and would not contribute to rupture. Furthermore, a simple 2.5 km shift of

the reservoir load relative to this location will also change the Coulomb stress change to negative. The main conclusion of Ge et al.'s (2009) paper based on Figure 2a is opposite to that based on both Figures 2b and 2c for the same model.

It is more appropriate to model the Coulomb stress changes in 3-D. The epicenter of the Wenchuan earthquake is significantly offset from the strike line of the two dimensional model (Figure 1 of Ge et al., 2009). We simplify Zipingpu reservoir to a $5\text{ km} \times 1\text{ km}$ rectangle

Figure 1 Location of Zipingpu reservoir and the seismicity pattern around the reservoir area. The red cross indicates the epicenter of Wenchuan earthquake reported by USGS. The yellow cross indicates the epicenter of Wenchuan earthquake reported by CEA.

Figure 2 Simulated change in effective Coulomb stress due to the load from the Zipingpu Reservoir. (a) Ge et al. (2009)'s result; (b) The result with Ge et al. (2009)'s model, but the dip is set to be 35° at the depth 14–15 km; (c) The result with Ge et al. (2009)'s model, but shift the reservoir 2.5 km left to let the reservoir cross the rupturing fault YB. The yellow cross indicates the epicenter of Wenchuan earthquake reported by CEA.

loading with the same water level of the reservoir impoundment described in Ge et al. (2009). We also use a fault dip of 35° , a strike of 229° and a rake 120° . Figure 3 shows the simulated effective Coulomb stress change on the initial rupturing fault induced by the reservoir with a 3-D model whose friction, diffusion and Poisson ratio parameters are the same of those of the 2-D model constructed by Ge et al. (2009). This 3-D model should be closer to the real situation than the 2-D model. Figure 3 shows that the effective Coulomb stress change around the initial rupturing area of Wenchuan earthquake is about -0.0010 MPa (for USGS's location) and -0.0017 MPa (for China Earthquake Administration's location). The stress change is too small and of the

wrong sign to trigger earthquake.

A further evidence is that seismicity data does not support any inference that the seismicity changed substantially after impoundment of the reservoir. Deng et al. (2010) analyzed the reservoir regional seismicity with events of magnitude > 1.0 before and after the reservoir impoundment time in detail and found that there were not any seismicity abnormal change traces. Additionally, Earthquake Administration of Sichuan Province set up an institute (Institute of Reservoir Earthquake Research) to monitor the seismicity in the reservoir region and a special seismic array with seven stations within the region 30.6°N – 31.4°N ; 103.1°E – 103.9°E . It began monitoring in 2004 (Hu, 2007), a year earlier than the time of

Figure 3 Simulated change in effective Coulomb stress on the rupturing fault YB with the 3-D model. (a) Induced Coulomb stress change on the fault on the day before Wenchuan earthquake occurrence. The red cross indicates the location of Wenchuan earthquake reported by USGS. The yellow cross indicates the location of Wenchuan earthquake reported by CEA; (b) Water level variation on time and Coulomb stress variations with time at the initial rupturing area. The origin of time is the reservoir impoundment time (September 30, 2005).

Zipingpu reservoir impoundment. The institute did not presented any reports on micro-seismicity abnormally increase around Zipingpu reservoir region, either. Huang (2008) has already reached a similar conclusion. He adopted RTL (Region-Time-Length) method to quantitatively analyze the characteristics of the seismicity changes prior to the Wenchuan earthquake occurrence and showed a seismic quiescence anomaly appeared during 2006–2007, which again suggests the reservoir impoundment did not trigger a regional micro-seismicity

increase.

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