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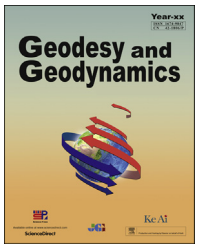

The effect of large reservoirs impoundment to the spatial and temporal variations of regional crustal deformation in Hubei Province, China

Wenbin Shen[a,b,*], *Xueqing Zhang*[a]

[a] *Department of Geophysics, School of Geodesy and Geomatics, Wuhan University, Wuhan 430079, China*
[b] *State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China*

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ABSTRACT

The total capacity of Three Gorges Reservoir (TGR) and Danjiangkou Reservoir (DJR) is large and has significant seasonal fluctuations, which give rise to crustal instability. In this research, we focus on studying the temporal and spatial variation of crustal deformation in Hubei Province caused by reservoir impoundment of TGR and DJR. The Digital Elevation Model, historical hydrological information, GPS monitoring data and load-induced deformation model are combined to monitor the crustal deformation. The modeled results indicate that in the trapezoidal area between the TGR and DJR, the average vertical deformations at different latitudes have different variation tendencies. The vertical deformation modulus and fluctuation amplitude are larger at the latitude of 33°N/32.5°N from 2003 to 2006 and at the latitude of 31°N/32.5°N from 2008 to 2014, while the latter are much larger than the former. Moreover, from 2008 to 2014, the frequency and the intensity of seismic activities are all enhanced significantly in this region. The modeled results at the GPS sites are consistent with the vertical displacement of GPS monitoring results in trends and the waveform. It can be inferred that the seasonal deformation is elastic. The horizontal deformation components have the same variation trends with that at each GPS monitoring station, which demonstrates that the whole region is moving toward the southeast. The spatial variation of crustal deformation demonstrates that the impoundment of TGR in 2003 causes significant vertical displacements, with the maximum modulus of 32 mm downward located in Xiangjiang River's estuary. When the water storage increases, the maximum value will become larger, and the location will move toward the upstream.

* *Corresponding author*. Department of Geophysics, School of Geodesy and Geomatics, Wuhan University, Wuhan 430079, China.
E-mail address: wbshen@sgg.whu.edu.cn (W. Shen).
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Besides, the earthquakes occurred more frequently in the region with maximum deformation modulus.

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1. Introduction

When a large reservoir is impounding, the surface load induced by the impoundment will increase rapidly, causing significant crustal deformation. The total capacity of Three Gorges Reservoir (TGR) is about 39.3 billion cubic meters, while the total capacity of Danjiangkou Reservoir (DJR) is about 29.05 billion cubic meters. Both of them are famous for their large capacity, and exhibits significant seasonal fluctuations, which lead to an increment of crustal instability. The seasonal fluctuation of the capacity is up to 38 billion cubic meters in total [1–3]. Therefore, studying the relationship between changes in crustal deformation and water loading increment is of great significance.

Previous studies have addressed the crustal deformation caused by the Three Gorges Project. Wang [4] calculated the water load-induced surface vertical displacements and level plane changes in the front reservoir area during the filling period and discussed the induced height change. The Green's function method and the PREM elastic Earth model were adopted in the study of Boy and Chao [5], which indicates that the annual geoid height increment is above the GRACE observational sensitivity. Wang et al. [6] modeled horizontal displacements induced by TGR impoundment. The longitudinal and latitudinal components of the horizontal displacements reach 8.2 and 7.7 mm respectively. Du et al. [7] studied the crustal movement of the TGR region from 1998 to 2003, the results show that the crustal activity of this region is relatively weak, with about 0–3 mm/yr relative motion between stations. The first impoundment of TGR results in vertical settlement of reservoir shore, and the crustal deformation is obvious with 10–40 mm subsidence and 5–10 mm relative deformation. Du et al. [8] conducted a model simulation about vertical deformation of 135-m water level of TGR area, combined with GPS data before and after the impoundment of the TGR. According to the comparison analyses, the geological structure of Xiangxi is relatively complex, and the movement trends of two sides of a river are obviously different. The lithospheric rigidity is stronger in Kushou, with stable geological condition combined digital elevation model (DEM) of the TGR with Farrell load elastic deformation theory, Qiao et al. [9] conducted a numerical simulation study about vertical deformation field of 135-m water level, showing maximum variations in Taiping'ao (−34 mm) and Xiangxi area (46.4 mm) compared with GPS monitoring data. Du et al. [10] demonstrated that the impounding water in June 2003 has induced transient displacement at the TGR dam and the emerging reservoir. GPS measurements after the first stage of water filling of the reservoir demonstrate that vertical subsidence caused by the impoundment is located in the segment of the reservoir from Maoping to Xiangxi. Wang [11] simulated the deformation caused by load of TGR using PREM model parameters and Gutenberg Bullen model. The simulation results show that the PREM model parameters are closer to the real parameters in situ. Liang and Du [12] simulated the vertical crustal deformation field caused by load of TGR with water level of 135 m, 156 m, and 175 m. The results show that the deformation field is consistent with the increment of water storage capacity in space, and the deformation value reducing toward the bank direction. Wu et al. [13] calculated the displacement field in TGR area using finite element method. The results show that there are 4 areas with extreme values: Badong, Guizhou, Niukou, Xintan. After the first time of water impoundment, earthquake of magnitude Ms2.5 plus occurred 4 times in the areas, and 14 times after the third time impoundment. Hu et al. [14] simulated the crustal vertical deformation field in TGR with water level of 135 m, 156 m, and 175 m by elastic finite element method using GPS observation data. And the results were compared with those calculated by Farrell's load-induced deformation model. The results also show that the maximum modulus of deformation is in Xiangxi. Wang et al. [15] modeled the surface gravity and displacement changes in the front area of TGR caused by water storage variations using elastic loading model. GPS time series at the sites were used to be compared with the modeled results. The results indicate that the ground gravity and the vertical displacement are more sensitive to water storage changes than the horizontal displacement.

In summary, there were no scholar to combine the water loading of TGR with DJR to study the crustal deformation in Hubei Province, and few scholars involved in the seasonal deformation variations. So, this paper will concentrate on the two aspects, and discuss if there was permanent deformation caused by the water loading variations (See Fig. 1).

2. Data and methodology

2.1. *Research area*

2.2. *The load-induced deformation model*

The Earth's elastic deformation occurs when the mass load varies. According to Farrel's improved load-induced