Analysis of the Effects of Rainfall and Groundwater on the Activities of the Baibaoshan Fault

Li Hong¹,²

¹ Beijing Earthquake Agency, Beijing, China, 100080
² Institute of Geology, China Earthquake Administration, Beijing, China, 100029
Email: lh@bjseis.gov.cn

Abstract The Babaoshan fault is one of the main faults in Beijing area. The cross-fault leveling in Niukouyu segment of the fault has been well monitored for many years. At the same time, rainfall and groundwater have obvious influence on leveling data. Based on the qualitative analysis of fault activity reflected by the change of EW direction leveling of Niukouyu segment from 1992 to 1998, a three-dimensional fault model is established to quantitatively explore the weakening effect of rainfall and groundwater on fault activity.

1. Introduction
Fault deformation observation can provide information for us to understand fault motion and stress accumulation. Theoretical and experimental studies have shown that the effects of rainfall and groundwater (fluid) on fault deformation can’t be ignored for faults exposed to the surface [1]. The reason is that rainfall infiltrates into deep fault through fault belt channel and affects fault activity. These possible factors should be considered in the analysis, determination and verification of deformation observation anomalies. Many scholars have carried out qualitative analysis and tried to explain the mechanism. The quantitative simulation analysis is carried out by taking the fixed-point leveling observation of Fangshan seismic station as an example.

2. Basic information of Fangshan seismic station
The fixed deformation monitoring seismic station of Fangshan is located in Niukouyu of Fangshan and on the southern segment of Babaoshan fault zone, which is one of the main faults in Beijing. Its altitude is about 70 meters. The outdoor leveling line is located north-east direction of the station (Fig.1).

The Babaoshan fault is located on the west side of the Beijing graben depression and the west of the fault is the West Beijing uplift. The fault is a compressive fault with a total length of about 60-70 km with strike of NNE or NE and dip of SE. It is an obvious boundary between the western mountain area and the eastern plain. The southern segment of the Babaoshan fault is covered by the Quaternary with a thickness of 20-40 meters, and the distribution of isochronous strata is not controlled by the fault, which indicates that there is no obvious vertical differential activity in the Quaternary [2].
3. Leveling observations data of EW direction of the Fangshan seismicstation

Leveling of EW direction of the Fangshan seismicstation was a cross-fault measure line observed from 1992. There were varying degrees of anomalies before the M6.2 Zhangbei earthquake on 10 January 1998, the M5.6 Datong-Yanggao earthquake on 1 November 1999 and the M5.1 earthquake Wenan on 4 July 2006. Meanwhile, Rainfall data from the station since 1993 show that, leveling observation of EW direction has some correlation with rainfall so make it displays certain annual variation. There is a correlation between rainfall and groundwater level (Limited to space, figures are not given here). When rainfall increases, water level rises generally, when rainfall reduces, water level drops. However, there is lag in the change of water level. A few years before the Zhangbei earthquake in 1998, leveling of EW direction of Fangshan seismicstation has stable annual variation period and alternate change of tension and compression. But one year before the Zhangbei earthquake, there was a continuous compression change instead of tension change during the rainy season (Fig.2), which shows the tectonic stress field is enhanced. In order to discuss the influence of rainfall and groundwater on level observation of fault, this paper focuses on the analysis of faults activity before Zhangbei earthquake in 1998.

Figure.1 Map of main fault and cross-fault displacement measure point in Beijing

Figure.2 EW Leveling and Rainfall of Fangshan seismicstation before Zhangbei Earthquake in 1998
The statistics of the time interval and variation of alternate change of tension and compression of EW leveling of Fangshan seismic station before Zhangbei earthquake in 1998 are given in Tab.1. According to the leveling observation, it is considered that the fault is in a relatively stable stress state under the combined action of tectonic stress and rainfall, groundwater and so on before the Zhangbei earthquake and it presents a more regular periodic tension change. The 3D fault model of Niukouyu segment of Babaoshan fault is established here to carry out quantitative analysis of the effect of rainfall and groundwater on the fault activity.

| Year     | Period          | Cumulative level change /mm | Mode of movement of upper wall to footwall | Property |
|----------|-----------------|-----------------------------|-----------------------------------------|----------|
| 1992     |                 | 0.89                        | relative rise                           | compression |
| 1992     | 2 Aug.-9 Aug.   | 0.46                        | relative decline                        | tension   |
| 1992-1993|                 | 0.76                        | relative rise                           | compression |
| 1993     | 12 June to 14 Sep. | 0.81                      | relative decline                        | tension   |
| 1993-1994|                 | 0.9                         | relative rise                           | compression |
| 1994     | 11 July to 30 July | 1.45                       | relative decline                        | tension   |
| 1994-1995|                 | 1.06                        | relative rise                           | compression |
| 1995     | 22 July to 22 Aug. | 1.03                       | relative decline                        | tension   |
| 1995-1996|                 | 1.34                        | relative rise                           | compression |
| 1996     | 8 July to 21 July | 0.72, 1.54                  | relative decline                        | tension   |
|          | 21 July to 23 Aug. | 0.82                       | relative decline                        | tension   |
| 1997     |                 |                            |                                          |           |
| 1996-1998|                 | 1.92                        | relative rise                           | compression |
| 1998     | 5 July to 25 July | 0.59                        | relative decline                        | tension   |

4. Establishment of 3D fault model and result test
Field investigation shows that Niukouyu segment of Fangshan fault is an inverse fault with upper wall of sinian suberathem limestone and footwall of carboniferous fine sandstone[2,3]. Outdoor Short Leveling site of Fangshan seismcstation is consisted of two measure segments. EW direction is a cross-fault line: down 1-down 2-up 1-NS direction is a line in same block: up 1-up 2. The length of EW measure line is about 100 meters. According regional geological conditions, we build a 3D geological model in which the strike and dip angle of fault is N50°E and S55°E respectively.

According to research finding of rock mechanics experiment[4], Babaoshan fault active state[5,6] and Inversion of deep velocity structure in the Capital area [7], combining with analysis of He Ping [8], we obtain the material parameters of the fault model of Niukouyu segment (Tab.2).

| Model medium | lithologic character | Density/kg·m-3 | Elastic module/GPa | Poisson ratio | Friction coefficient |
|--------------|----------------------|----------------|-------------------|--------------|---------------------|
| Fault        | Clay, Palygorskite    | 2100           | 2.0×10            | 0.25         | 0.60                |
| Upperwall of fault | Sinian Suberathem limestone | 2600           | 5.5×10            | 0.25         | -                   |
| Footwall of fault | Carboniferous fine sandstone | 2350           | 3.0×10            | 0.25         | -                   |

On basis of 3D Geological model, we build 3D finite element model (fig.3). The rectangular region in the figure is the target region. We expand the range of the model to avoid the influence of the boundary effect. The north-west, south-east boundary is about 1 km and the south-west and north-east boundary is about 1.1 km. The NW-SE displacement of the whole block is ignored because of the 1km scale of the model. The boundary constraints are shown in fig.3, the NW and SE boundary are fixed, NE and SW boundary are applied some pressure according to the tectonic stress field in the capital area, the bottom is vertical fixed and the surface is free.
Figure 3 3D geological model and finite element model

The point A and B that cross the fault, represent the two measure points of EW leveling of Niukouyu. We can get the vertical displacement change of A and B by simulation so to analyze deformation and movement of fault.

We test the rationality of results by comparing the direction, magnitude and vector of regional background principle compressive strain field with other research result. For example, the result on Babaoshan-Huangzhuang-Gaoliying fault by Che Zhaohong [9] shows the maximum principal strain field direction is N57°E and magnitude order is $7.1 \times 10^{-6}$. They are basically the same indicating the boundary constraints are reasonable.

5. Simulation of the weakening effect of rainfall and groundwater on faults
When the rainfall is large in every summer, the rainwater penetrates down through the faults exposed to the surface, which weakens the faults. Here, the weakening effect of the faults is characterized by reducing the friction coefficient. The elevation changes of the measured points A、B of the cross-fault are calculated and the fault motion caused by weakening is obtained.

According to the simulation results (Tab.3), when the rainfall is large, the water storage near the fault increases, and on the other hand, the rainfall penetrates through the fault, weakening the fault, making it easy to slide, resulting in the vertical change of point A and point B. It shows tensile fault activity that the upper wall declined relative to the footwall. When the friction coefficient is weakened from 0.6 to 0.5, the leveling change is 0.242 mm, and 0.35 mm when friction coefficient is 0.4, 1.47 mm when friction coefficient is 0.3. It can be seen that the level change increases with the strengthening of fault weakening.

Table 3 Simulation results of fault weakening effect

| Friction coefficient | Fault mode                     | Vertical variation /mm | motion properties |
|----------------------|--------------------------------|------------------------|-------------------|
| 0.6                  | baseline                       | baseline               | baseline          |
| 0.5                  | relative decline of upper wall | 0.242                  | tension           |
| 0.4                  | relative decline of upper wall | 0.35                   | tension           |
| 0.3                  | relative decline of upper wall | 1.47                   | tension           |

6. Summary
Combined the observation data from the fixed point level EW of Niukouyu in Fangshan from 1992 to 1998 with the statistical analysis of tension and compression fault activity, some preliminary understandings are obtained.

(1). Niukouyu segment of Babaoshan fault is characterized stable alternate tension and compression motion during 1992 to 1996 under the combined affection of regional tectonic stress field, rainfall and groundwater.
(2). The observation of cross-fault leveling of Niukouyu of Fangshan showed a regular annual variation pattern during 1992 to 1996. The fault is characterized by tensional activity with the increase of rainfall in summer every year.

(3). The tensional activity makes the upper wall of the fault a decline about 0.46-1.45 mm to the footwall every summer.

(4). Simulation shows the weakening effect of rainfall and groundwater on the fault makes the fault tensile motion. The vertical variation is related to the degree of fault weakening.

(5). What can’t be ignored is the periodic tension motion of fault leveling in this period is not only affected by rainfall, but also closely related to the local tectonic stress and the mechanical properties of fault.

Acknowledgements
Thanks for the fund support of Three Integration Project (3JH-202001002), Earthquake Tracking project(2020010503) and Earthquake Technology Spark Plan project(XH19001Y).

Author in Brief
Li Hong, Ph. D. major in Tectonic Geology, senior engineer of Beijing Earthquake Agency, mainly engaged in seismic comprehensive analysis and geodynamics research.

Reference
[1] Scholz C H.(1990). The Mechanics of Earthquakes and Faulting [M]. Cambridge University Press,461.
[2] Xu jie, Wang Liangmou, Fang Zhongjing, et al.(1992).Preliminary analysis of the tectonic activities of Babaoshan and Huangzhuang-Gaoliying faults in Beijing area [J]. North China Earthquake Sciences, 10(3) :1-10. (in Chinese)
[3] Lu Mingyong, Niu Anfu, Bai Changqing,et al.(2006). Preliminary study on relation of short term and impending earthquake anomalies between groundwater level and crustal deformation and the identification method of anomalies[J]. Journal of Seismological Research, 29(1):1319. (in Chinese)
[4] Ye Jinhan, Xia Wanren, Chen Yuxing.(1991). Experimental research on basic mechanical properties of Rock [J], Water Conservancy and Hydropower Technology, 1:24-28. (in Chinese)
[5] Jiao Qing, Qiu Zehua, Fan Guosheng.(2005). Analysis on recent tectonic activity and seismicity of Babaoshan-Huangzhuang-Gaoliying fault in Beijing region [J]. Journal of Geodesy and Geodynamics, 25(4):50-54. (in Chinese)
[6] Huang Fuqiong, Chen Yong, Bai Changqing, et al.(2005). The correlation of deformation behavior with precipitation and groundwater of the Babaoshan fault in Beijing [J]. Acta Seismologica Sinica, 27(6):637-646.(in Chinese)
[7] Jia Shixu, Zhang Xiankang, Fang Shengming.(2001). Research on the crustal structure and evolution of different blocks in North China rift-depression basin [J], Earth Science Frontiers(China University of Geosciences,Beijing), 8(2):259-266.
[8] He Ping (2010).Study on the mechanics of cross-fault leveling change by the finite element method[D], Institute of Earthquake Forecasting, CEA. (in Chinese)
[9] Che Zhaohong, Zhao Chongkun, Liu Tianhai.(1994). Study of local earth strain field in the Capital circle[J],Crustal Deformation and Earthquake, 14(1):32-37. (in Chinese)