IMPACT OF THE RESERVOIR INDUCED SEISMICITY ON THREE GORGES PROJECT

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ABSTRACT:
As the world's famous and grand water project, Three Gorges Reservoir has the most comprehensive means in monitoring network, including digital remote sensing seismic network, crustal deformation monitoring network and groundwater observation wells net. Many years of continuous monitoring provide us precious data materials, which lay a solid foundation to study the reservoir induced seismicity in Three Gorges area. The existing monitoring data show that the number and frequency of earthquakes after water impoundment increase continuously, that is, water storage indeed induce some earthquakes, but the strength and location are basically same with past's. According to the deformation monitoring and gravity field analysis, the biggest vertical deformation area and gravity change area are still in Xiangxi after water impoundment. Based on those monitoring results, we predict that earthquakes below a magnitude of 4.5 will occur after the third water impoundment(elevation of 175m),however, the intensity will not exceed Ⅵ.

KEYWORDS:
Three Gorges Reservoir, digital monitoring network, crustal deformation, groundwater, gravity field, reservoir induced seismicity

1. INTRODUCTION

The worldwide famous Yangtze River Three Gorges Project, is currently the world's largest water control project, while it plays important roles in flood control, power generation, shipping and other important efficiencies, the impact of reservoir induced seismicity is an inevitably scientific issue. The impounding process is divided into three phases, with the highest elevation of 175m. After the first and the second stage completed, water loading has changed the geological and tectonic earthquake environment of Three Gorges area, even a series of microseismicity. In order to protect the security of the Three Gorges Project and the lower reaches of the reservoir area, as well as keep the social stability and economic development, the Three Gorges reservoir seismic monitoring is of great practical significance.

2. THREE GORGES DIGITAL MONITORING NETWORK

Three Gorges digital telemetry network includes digital remote sensing seismic network, crustal deformation monitoring network and groundwater observation wells net (as shown in Fig.1).

Digital telemetry seismic network is consisted of 24 all-digital high-gain constant seismic telemetry, two digital strong seismic stations, eight mobile digital monitoring instruments, multi-channel microwave relay communications system and network centers, and network centre connects earthquake monitoring centre with wide-area network. 24 sub-stations are equipped with high sensitivity seismic devices, 22 of which emplaced in the important focus area, 2 stations emplaced in the general area. The surveillance monitoring capacity in focusing region reaches ML0.5, and that of general monitoring zone monitoring capacity is ML1.0.

Crustal deformation monitoring network is a regional network located in the Sandouping - Badong section of Three Gorges reservoir area and the neighboring areas, which integrates global positioning system (GPS), precision laser ranging, Tong Mountain deformation observation system, precision gravity and precise leveling measurement. In Space, point, line, side connects and in time, long, medium, short take into account. It consists of 3 GPS base stations, 21 GPS mobile observation pots, a regional precise leveling network, a regional gravity network, seven laser ranging network, six short leveling lines, a Tong Mountain deformation Stations and three reservoir basin settlement monitoring lines, two reservoir basin monitoring pots. GPS base stations and Tong Mountain continuous deformation monitoring stations are used to monitor the crustal deformation of reservoir area; other monitoring projects are used in regular crustal deformation monitoring.

Well network is consisted of eight groundwater observation wells, setting up a total of 25 measured items, including water level, water temperature, radon gas and the temperature, air pressure, rainfall, and other dynamic parameters, and observation data can automatically be transferred to the earthquake monitoring terminus.

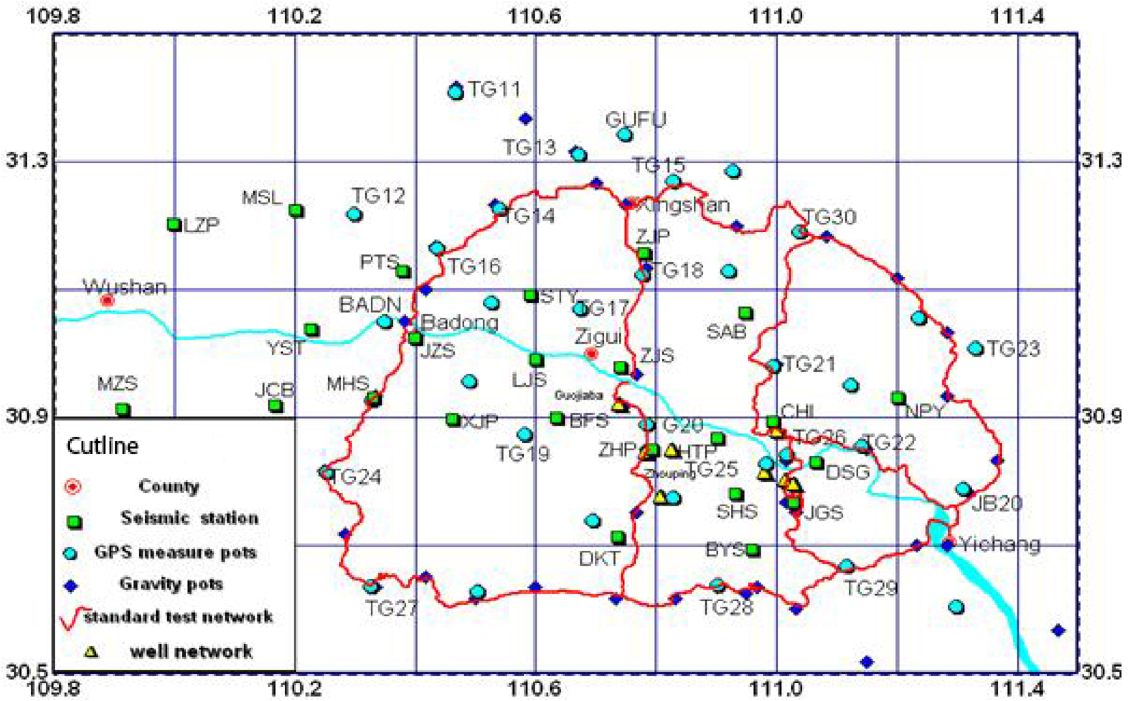


Fig. 1 Distribution of the Three Gorges digital telemetry network

3. MONITORING RESULTS

3.1. Seismic Changes in Space and Time

Earthquake is fewer in the range of 20km along the Yangtze River, from January, 2001 ,when the Three Gorges digital network operated well till the first impoundment in May, 2003.The earthquake number of ML≥1.0 is 136, and the monthly frequency is about 11, among which the number of ML≥3.0 is 4, and the biggest one is ML4.1. Most of them belong to tectonic earthquake (Fig. 2). However, the earthquake frequency significantly

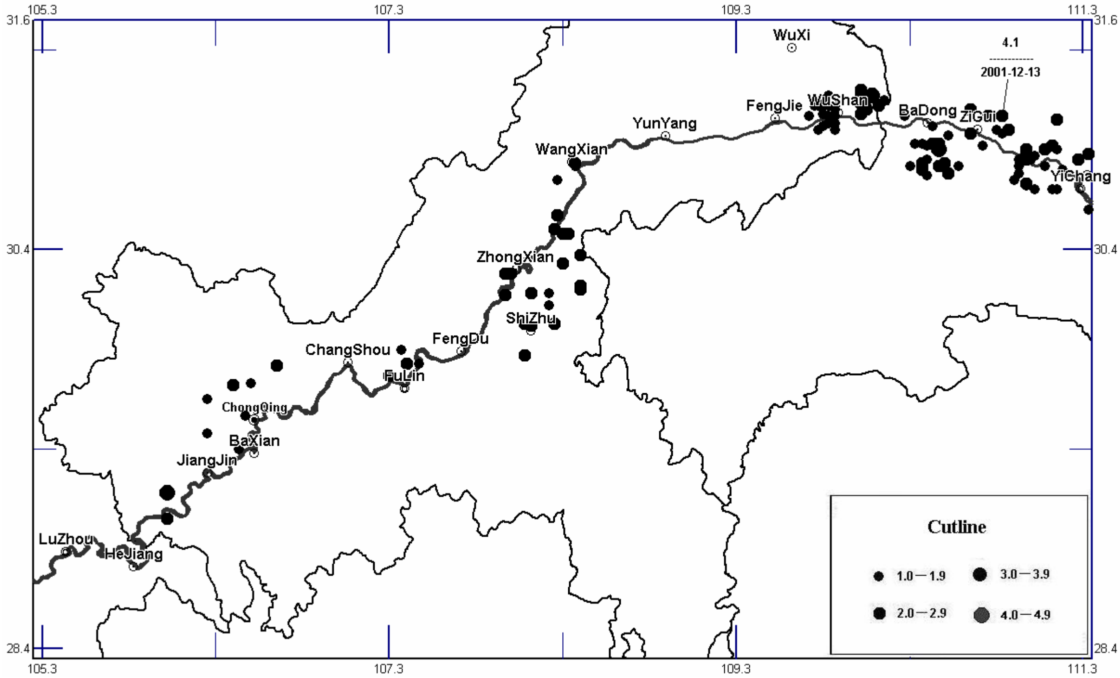


Figure2 Distribution of earthquake in time and space from 2001.01.01 to 2003.05.31

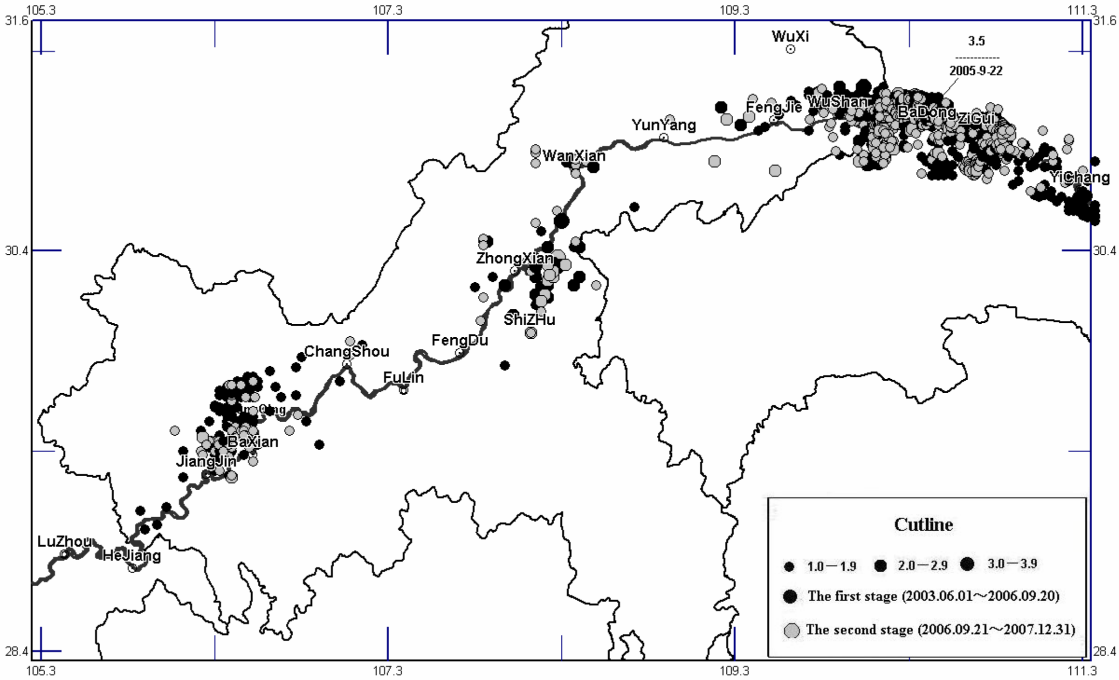


Figure3 Distribution of earthquake in time and space from 2003.06.01 to 2007.12.31

increased after the first impoundment. From June 2003 to September 2006, the total earthquake number of ML ≥1.0 increased to 1211, correspondingly, the month frequency increased to 31. Earthquake with ML≥3.0 is 10, and the biggest is ML3.5. On 21st, September, 2006, the second water impoundment started, during the period, the number of ML≥1.0 and ML≥3.0 separately is 909 and 3, ML3.0 is the maximum. From those statistics, it is easy to see that the frequency increased significantly. But in space, the earthquake mainly still distributes in the Zigui and Badong segment (Fig. 3).
The earthquake number of ML≥3.0 hasn't changed a lot before and after water impoundment, that is, the intensity of the earthquake still remain basically unchanged. Choosing the micro-earthquakes happened after water impoundment, and making use of the digital wave analysis, connecting with macro investigation, it is found that most of these micro earthquakes have their own characteristics, such as smaller magnitude, higher epicenter intensity, faster attenuation(Figure 3), shallower source and so on, which all are distinguished from the tectonic earthquake. And most of these micro earthquakes have a close relationship with geological body existing in the shallow surface. According to the earthquake mechanism, we can classify them into mine earthquake, karst collapsed earthquake, blasting, landslide earthquake and other types (Li, 2003; Di, 2004)

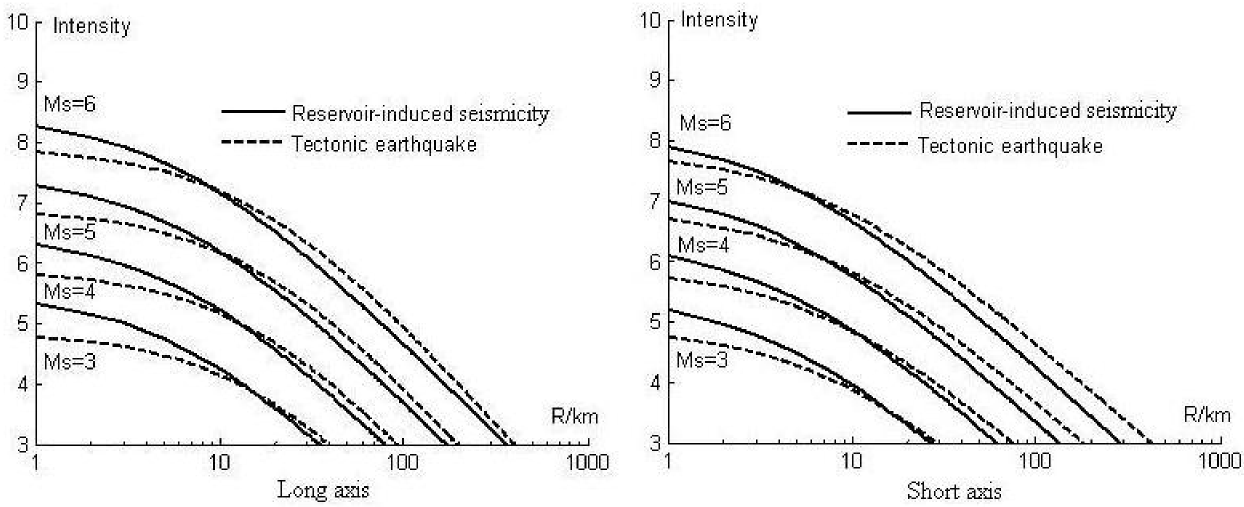
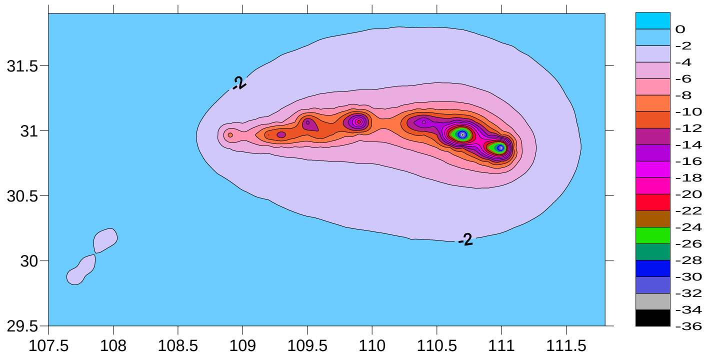


Figure 3 the attenuation curves of intensity of RIS and tectonic earthquakes in the Three Gorges region (Kong, 2006)

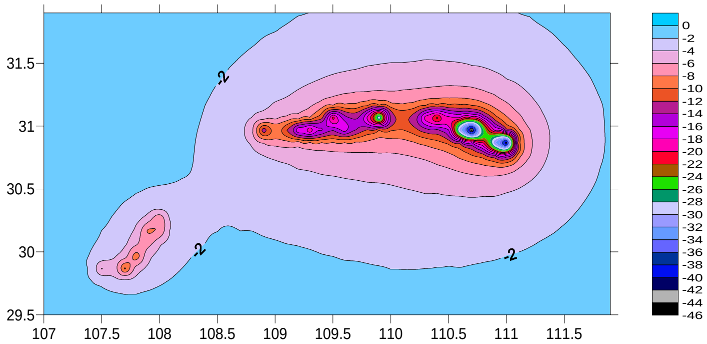
3.2. Analysis on Deformation Monitoring Results

The obvious changes of elevation of GPS stations after the first stage impounding, reflect that the impounding has important impact on crustal vertical displacement. The main vertical deformation region distributes from the dam site to the Xiangxi sector, and the deformation near the shore is about-20~-40mm, whereas near the shore in Badong sector, the deformation reduces to -10mm or so (Du, 2004). Vertical deformation shows a trend that the deformation reduces as the distance from the core of reservoir increases, the reasons of which, in our opinion, may be due to the increasement value of water load is not big enough when it impounds to the elevation of 135m, and the effect range is limited.
We have done some researches on the comprehensive simulation of the crustal deformation after the 156m and 175m water storage with Green function (Fig.4), which includes the digital terrain model extraction based on the SRTM, water body model, and deformation simulation and so on. The result of simulations illustrate that the

vertical deformation zones concentrate on the Xiangxi valley in the head area, and two peaks separately emerge in the dam site and near the Xiangxi river, among which, the biggest deformation is near the Xiangxi river. The peaks of the deformation values caused by the second and the third stage impounding are -36mm and -46mm, however, the deformation in the bottom of the reservoir is not obvious.



(a)156m elevation after 2nd impoundment



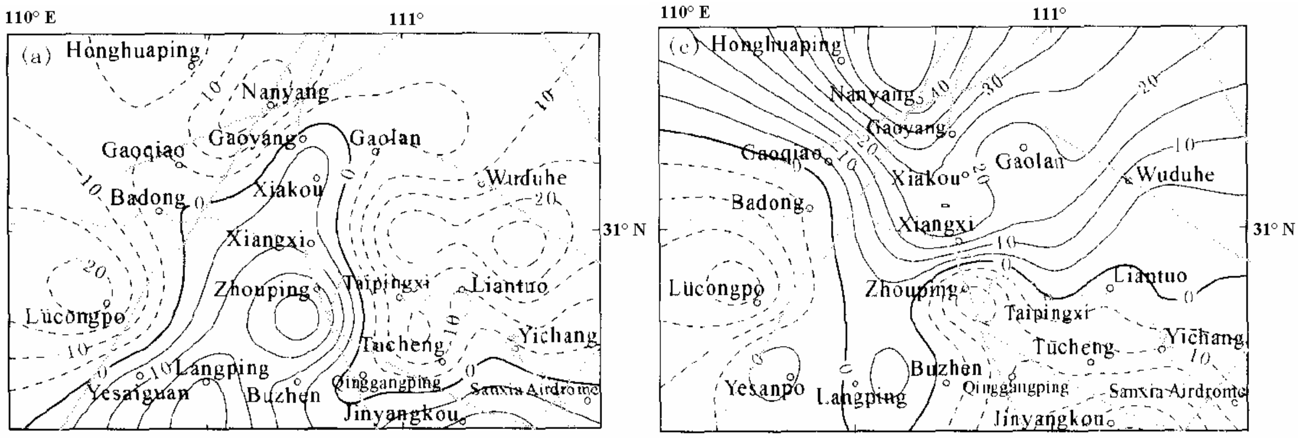
(b)175m elevation after 3rd impoundment

Figure 4 Vertical deformation field simulations caused by water loading after 156m and 175m water impoundment

3.3. Gravity Field Changes Before and After Water Impoundment

The first water storage has great effect on the regional gravity field in the dam area, and the gravity effect resulted from water loading is of great significance. The gravity field is characterized by great magnitude order (the maximum gravity change is 200×10^{-8}m/s^2), small scope (it is about 5km offshore that the gravity change can be observed), fast attenuation with the long distance far away from the reservoir basin (Fig.5). But this kind of effect is mainly limited in terms of amplitude and range, which is not big enough to affect the space distribution of the gross gravity effect, but proves that the crust in the dam area is stable after impounding. And the change caused by ground water level change is regional and the impact of rainfall on it should not be neglected. At head area of the reservoir, the maximum gravity change is near Xiangxi.

The variation of regional gravity approximately accords with the change of water level in the Three Gorges reservoir during the second water storage, but in the head area of reservoir, it has great difference contrasting with the first water impounding. The gravity changes in the south and north sides of the reservoir are extremely dissymmetric. And the gravity field in the north side of the reservoir changes greatly and attenuates slowly; while the south side has small changes and attenuates quickly. In the Xiangxi segment, the variation of gravity is more regular and presents the characteristics that the gravity changes in the south side are stronger than that in the north one, taking basically the Yangtze River as the axis of symmetry (Sun, 2007). The observation results confirm that the maximum gravity change region is still in Xiangxi segment after the second impoundment.



(a) October,2002-April,2003 (b)July,2003-October,2003

Figure 5 Relative changes of gravity field in the head area of Three Gorges Reservoir(unit:$10^{-8}m/s^2$) (Sun, 2004)

3.4. Groundwater Monitoring Results

The first and second water impoundment start separately in May,2003 and September, 2006, with the elevation of reservoir water level, the earthquake month frequency increased obviously(Fig.6), at the same time, the groundwater also rises(Fig.7).

Three Gorges water level changes can be contributed to the two main factors: one is the water content changes in aquifer caused by rainfall, the other aquifer stress - strain state changes caused by atmospheric and tidal pressure. Deducted from rainfall, atmospheric pressure and tidal pressure, the water level changes mainly is correlated with water load , for new water load makes groundwater aquifers stress increase, and volume be compressed, then the water level rises.

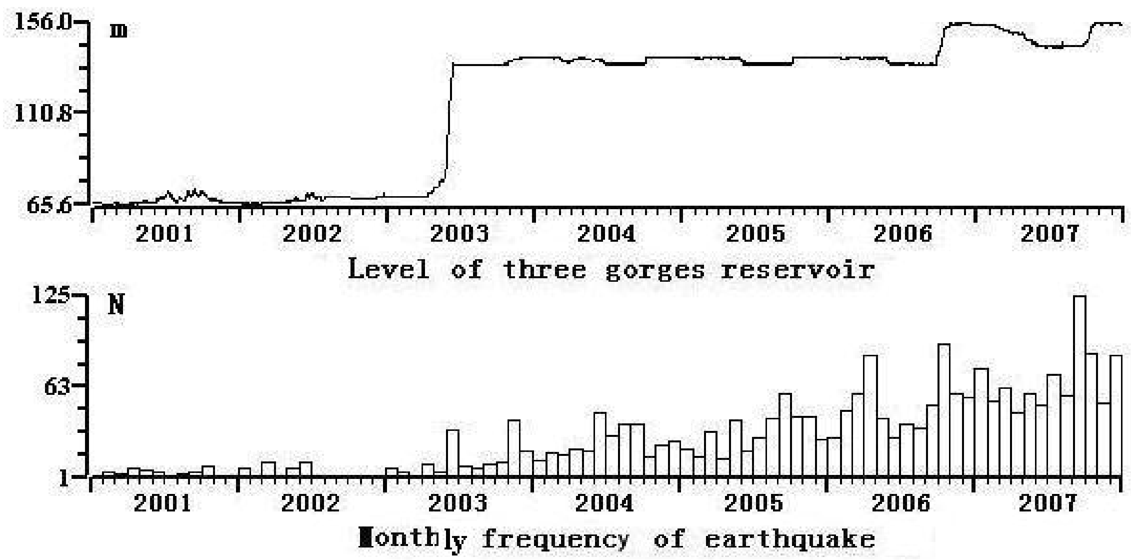


Figure 6 Relationships among the changes of reservoir level and earthquake monthly frequency

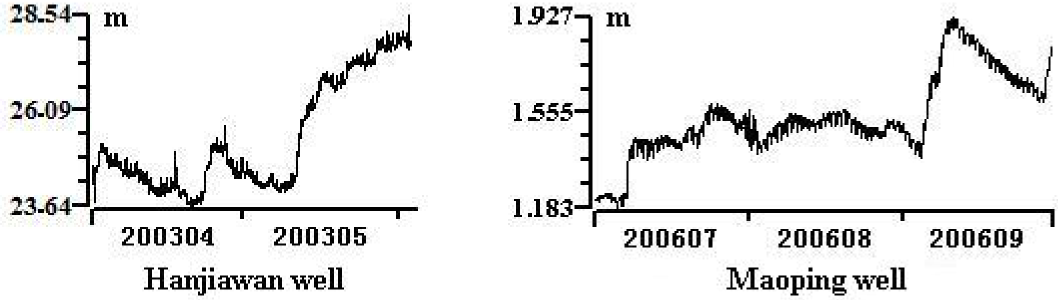


Figure 7 The variation curves of groundwater level

Having strong ability to respond to crustal stress and strain, Three Gorges well network has a certain ability to monitor the earthquake precursors occurring in the neighboring areas (Zhang, 2007). An earthquake with ML3.5 occurring in Badong, on 22nd, September, 2005(50km away from the well network) is a good case in point. Before the earthquake, the W1, W3 and W7 show the step changes of rapid rise or drop, and before that, neither the air pressure has significant ups and downs, nor rain interferences, so we think it is credible to take those changes as abnormality before earthquake. From 2006 till now, there isn't earthquakes with ML>3.0 out of the range of 50km, nor other precursor abnormalities.

4. CONCLUSIONS

The results based on analysis of existing real-time monitoring data and historical data are showed as follows:
1) Since Three Gorges Reservoir impounding in mid-May 2003, together with the reservoir water level rising continuously, the impact of huge reservoir loading on the gravity field, crustal stress-strain field, underground fluid field, and the seismological environment of the Three Gorges reservoir area and the neighbor areas could not be ignored, which has caused a series of typical reservoir induced seismicity;
2) It has induced a lot of microseismicity below a magnitude of 3.5 take place after water storage without destructive earthquake until now. In the monitoring area, compared the earthquakes before impoundment with ones after, it is obviously seen that the seismic location and intensity hasn't changed, basically within the forecasting scope in the early stage, only the frequency of microseism markedly increases.
3) The existing monitoring materials show that the Three Gorges Reservoir impounding will induce earthquakes with low magnitude. Moreover, this change in local water environment will continue to affect the earthquakes in the Three Gorges reservoir area, the geological environment changes and regional stress field adjustments. According to that, we can predict that only earthquake weaker than magnitude 4.5 takes place when the water level increases to 175m in 2009.
4) Comparing the attenuation of tectonic earthquake with reservoir induced seismicity; it is shown that the reservoir induced seismicity has the character of shallower source, higher epicenter intensity and smaller affected areas. In the feeling areas, the speed of intensity and acceleration attenuation of reservoir induced seismicity is faster than that of tectonic earthquake. By contrast, there is remarkable difference between the intensity of the both tectonic earthquake and reservoir induced seismicity with high magnitude in the potential source of the Three Gorges, the former one, stronger than latter's, may reach Ⅵ.
5) The increase rate of water load is controlled by means of slow and step-by-step impoundment, which

decreases underground stress-strain field changes and the sudden increase in speed of material changes (including groundwater seepage). It has not only greatly reduced the reservoir-induced seismicity magnitude, but also provided experience for following storage;

Therefore, the reservoir-induced seismicity monitoring studying on the Three Gorges Reservoir area is of great scientific and practical significance.

ACKNOWLEDGEMENTS

It is acknowledages that this research has been supported by National Natural Science Foundation (No. 40674019) ,Public Welfare Program of Science Department (No.2004DIB3J131) and National Science and Technology Support Program (No.2006BAC01B04-02-02) of China. Also, thanks are extended to Shen Chongyang, Du Ruilin, Luo Junqiu, Zhang Weihua, Kong Yuyang and so on for their comments and helpful suggestions.

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