INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

Microseismic Monitoring at Tokuyama Dam and Its Reservoir Area

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ABSTRACT:
Tokuyama Dam, has the largest reservoir capacity in Japan is close to both the Neodani fault, the source fault of the Nobi Earthquake, and the active Ibigawa fault. As such, the Japan Water Agency (JWA) has continued microseismic monitoring since 1976 before construction of Tokuyama Dam to monitor the impact of impounding.

Microseismicity was monitored with a microseismic monitoring system installed around reservoir area. Some data is missing, especially from winter periods due to heavy snowfall in the mountainous region, but seismic instrumentation around the dam recorded substantially more seismic events than Japan Meteorological Agency (JMA) due to equipment updates and the high concentration of monitoring points in a confined area. Monitoring results were organized to examine the impact on seismic activity before and after impounding. No significant changes in seismic activity were observed either in the vicinity of the dam or at a range of 20 km from the dam according to comparisons of seismic clusters in each area before and after impounding. JMA results were similarly compiled, and similarly found no significant changes in seismic activity from before and after impounding.

Keywords: micoseismic monitoring, Reservoir Induced Seismicity(RTS)

1. INTRODUCTION

Tokuyama Dam is a large dam, 161 m high with a reservoir capacity of 660 million m^3 and completed in 2008 by the JWA. Located on Ibi River in Ibigawa, Gifu Prefecture, it is used for flood control, water supply and power generation.

Due to its proximity to both the Neodani fault source fault of the Nobi Earthquake and the active Ibigawa fault JWA has monitored microseismic activity since 1976 before construction of Tokuyama Dam to monitor the impact of impounding.

This paper summarizes monitoring results from recent years and compares seismic activity before and after impounding.

2. DAM RESERVOIRS AND SEISMIC ACTIVITY

In general, the physical causal relationship between dam reservoirs and seismic activity is not clear.. However, in a previous paper, Okamoto studied seismic activity near Japanese dams based on JMA seismic monitoring results 10 years before and after impoundings, focusing on seismic events of Mj (JMA Magnitude)3.0 or higher, and concluded that no medium sized or larger seismic events occurred [Okamoto, 1985]. There are examples of reservoir triggered seismicity (RTS) at Koyna Dam and other foreign dams, but the International Commission on Large Dams (ICOLD) points out that, "Since records did not exist on the local seismicity prior to dam construction, there are still doubts whether these large earthquakes have actually been triggered by the reservoirs." [ICOLD, 2010]

3. SEISMIC MONITORING IN THE TOKUYAMA DAM AREA

JMA records seismic records to assist in disaster prevention and regularly publishes the results in ”The Seismological and Volcanological Bulletin of Japan ”[JMA]. So we compared seismic records of JMA and JWA, to understand the characteristics of both seismic monitoring and to evaluate of seismic activity on the basis of the results.

3.1. JMA Seismic Monitoring

The Upper of Figure 1 is a plot of the JMA monitoring points within a 100km square of Tokuyama Dam. It is unclear how many monitoring points JMA uses to determine the hypocenter and magnitude, but considering their purposes, it is reasonable to ignore calculating microseismics of Mj<0. Figure 2 gives a time line summary of JMA monitoring. The oldest earthquake in this record is from 1926. Since integrating monitoring points with the National Research Institute for Earth Science and Disaster Prevention [NIED] and universities, JMA has dramatically improved the sensitivity of its seismic monitoring in recent years.

3.2. Tokuyama Dam Microseismic Monitoring

Meanwhile, JWA has monitored micro seismicity at Tokuyama Dam since 1976. JWA originally calculated hypocenter and magnitude based on waveform analog records, it was digitized the process along with equipment upgrades. Since 2003, JWA have calculate hypocenters in post-processing based on continuous monitoring records, additional data at Niu Dam.

The current monitoring grid is given in the lower part of Fig.1, and the measurement status of each monitoring station is given in Figure 3. In Fig.3, the solid lines denote periods when monitoring stations were functional, and the blanks denote periods when monitoring was failed. The Obanashi and Tonyu monitoring stations were added after monitoring had begun. Each of the Dams are in areas of heavy snowfall, so we have issues with missing data due to disruptions in communications and blackout.

To improve this, JWA is working to ensure stable seismic monitoring by improving the sensitivity of records of individual monitoring points and arranging multiple monitoring points, as Obanashi and Tonyu.

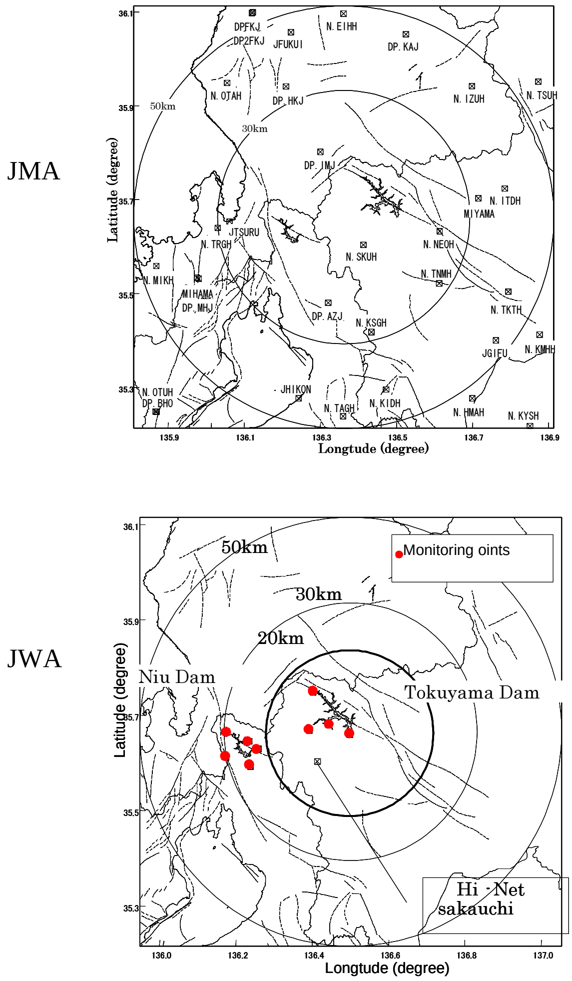

Figure 1. Seismic monitoring points around Tokuyama Dam

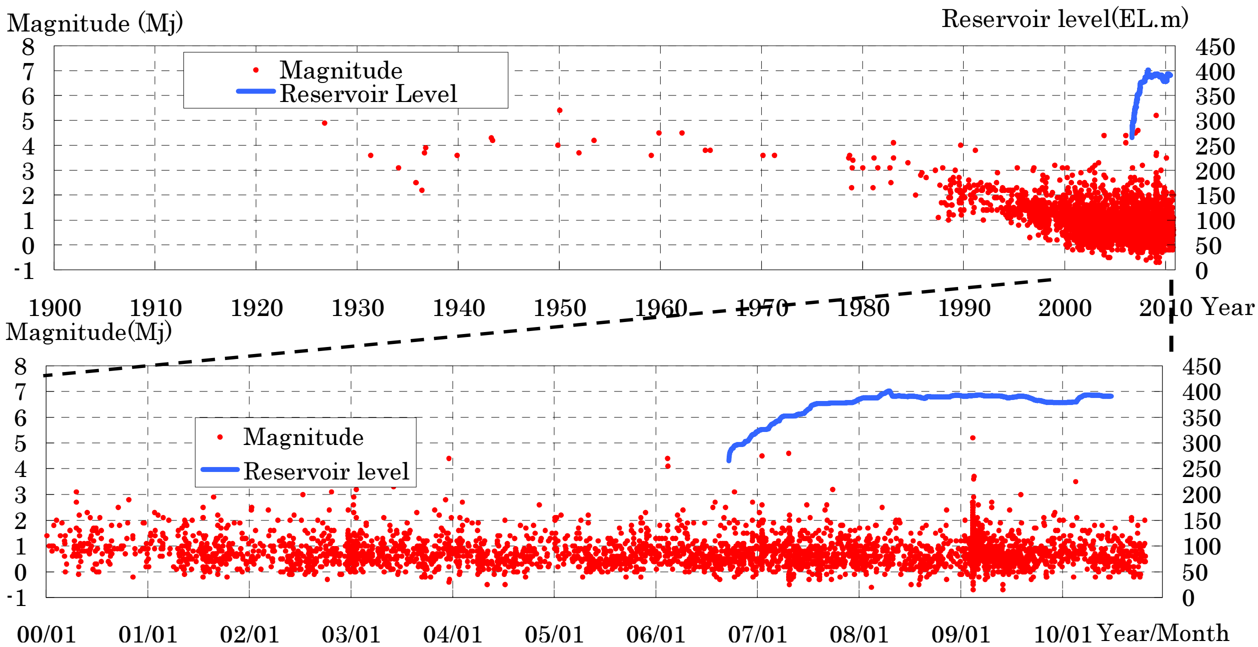

Figure 2. Seismic events Occurrence near Tokuyama Dam (JMA)

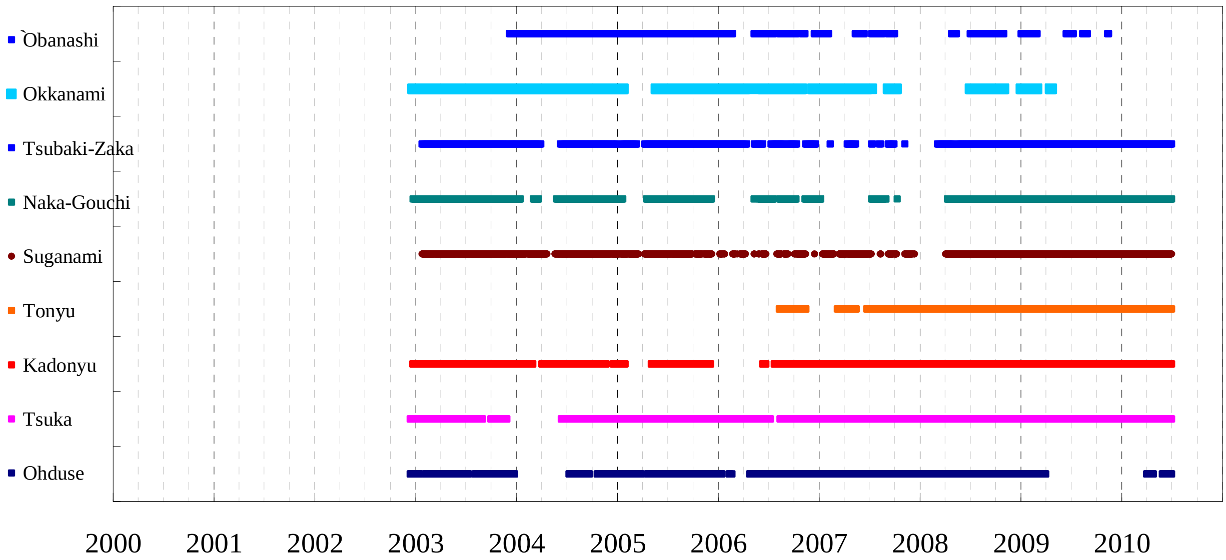

Figure 3. : JWA Seismic Measurement Status

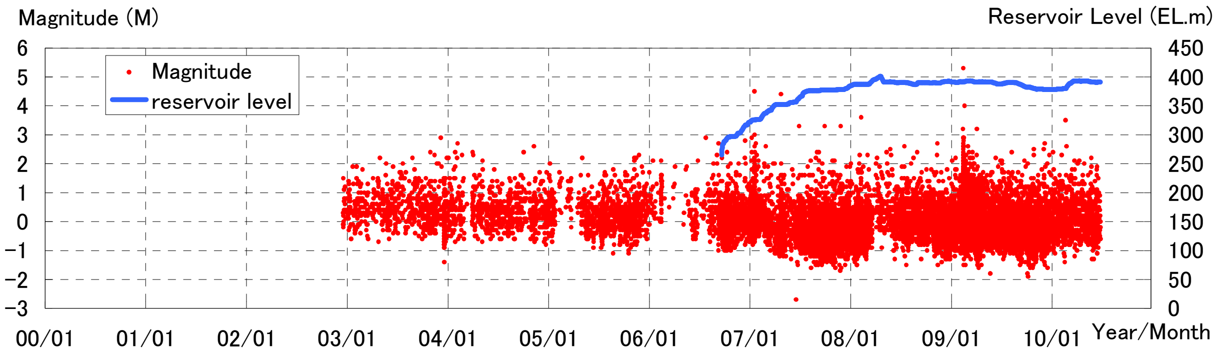

Figure 4. Seismic events Occurrence near Tokuyama Dam (JWA)

Figure 4 shows JWA seismic monitoring results within the same range as in Lower of Fig.2. As JWA calculate Magnitude by JWA's seismograph, this paper describes JWA results by "M" and JMA results by "Mj". Changes can be seen in the minimum magnitude monitored by period. This denotes that failures in monitoring due to communications and blackout. Weather and other factors impact monitoring sensitivity. Regardless, the minimum magnitude observed by JWA is smaller than that of JMA for almost all periods. This is considered to be due to the concentration of monitoring points established in narrow arera of near the dam site. Figure 5 shows a planar distribution of the observed seismicity. The figure plots all the hypocenters within a 40 km square and depths of 20 km or less. From December 2002 to June 2010, JWA monitoring recorded 14,249 seismic events in this area, in the other hand JMA seismic monitoring recorded 2,912.

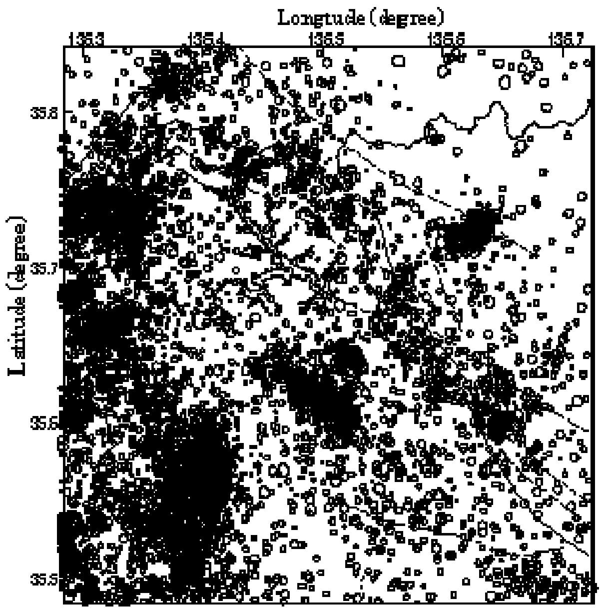

Figure 5. Planar Distribution of Observed seismic events (JWA)

4. EVALUATION OF SEISMIC ACTIVITY

4.1. Evaluations of Reservoir Triggered Seismicity in Past Documentation

According to ICOLD, reservoir triggered seismicity (RTS) phenomena are described as follows [ICOLD, 2009]:

- RTS occurs in shallow locations near reservoirs.
- In most cases the activity starts soon after the beginning of impounding and grows with reservoir levels, restarting as a rule after quick changes in reservoir levels.
- There is a trend indicating that greater time difference between the start of impounding and the maximum triggered shock yields a large maximum shock.
- The ratio between maximum shock and the highest aftershock is higher than in the case of usual seismic events.
- From frequency-magnitude relations, triggered seismicity indicates large b-values (will be explained in 4.3).[Logani, et.al,1979]:

We evaluate JMA and JWA seismic monitoring in accordance with the characteristics of triggered seismicity given in past literature and look for any triggered seismicity. As shown in 3., we confirm the changing circumstances of seismic events over time for JMA as their stable monitoring, but observed few seismic events. Meanwhile, we organize JWA results by seismic distribution and frequency-magnitude relations as the JWA seismographs were able to capture smaller seismic events, but affected by missing data and other issues.

4.2. Relationship between Reservoir Level and Numbers of Seismic Events

Figure 6 shows the numbers of seismic events of Mj1.0 or larger in each month from 2000-2010. According to Fig. 6, there was a large peak in February 2009, which is due to a Mj 5.2 shock, occurred in a area of 15 km west to the dam site, and its aftershocks. This shock was described as follows: "the strike of aftershock distribution is consistent with the nodal planes of focal mechanism solutions for the main shock, and is also consistent with local fault strikes and arrangement of local shock clusters."[DPRI, 2009] With the hypocenter being 15 km away from the dam and the b-value (will be explained in 4.3) for the area , including aftershocks, is 0.9. We thus surmise that it cannot be inferred that this seismic events was triggered by the reservoir.

There were no other outstanding or trending increases in seismic events along with reservoir levels, no significant changes from before to after impounding were seen looking at relationship between reservoir level and numbers of seismic events.

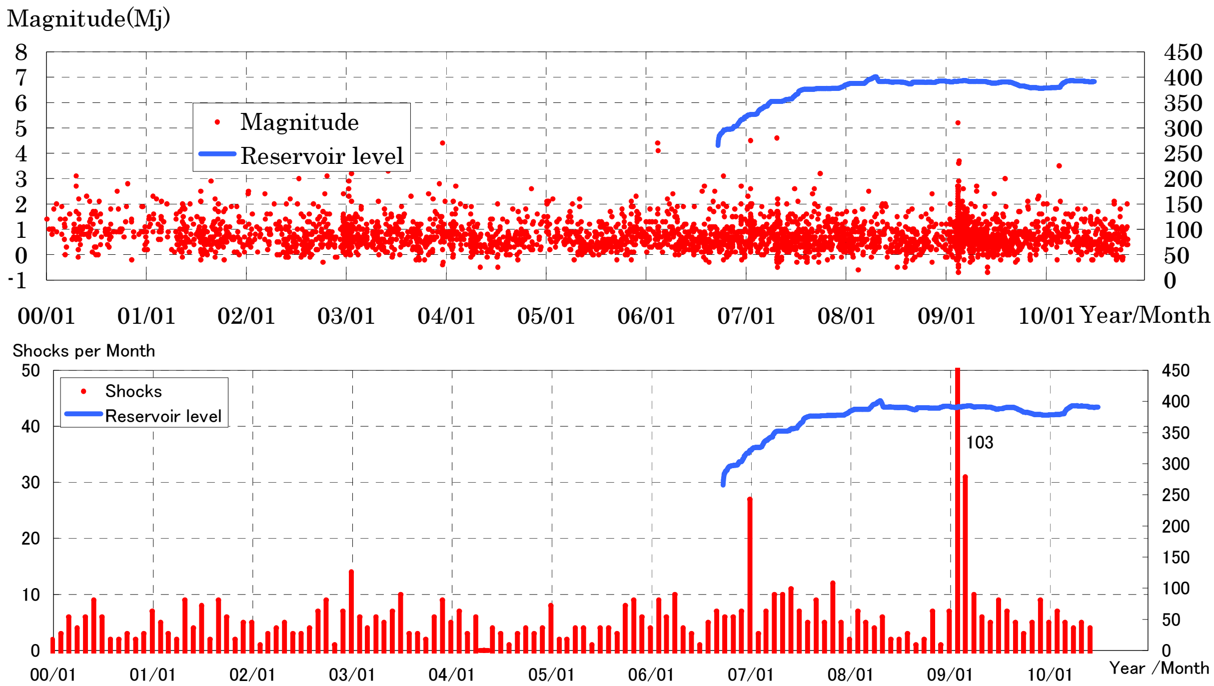

Figure 6. M>1.0 Shocks near Tokuyama Dam per month (JMA)

4.3. Relationship between Frequency-Magnitude (Using Gutenberg-Richter Law)

The Gutenberg, Richter law [Gutenberg et, al. 1954](Eq.1) expresses the relationship between the magnitude and total number of seismic events in any given region and time period.

$$\log N = a - bM \quad (1)$$

Where :

N : *Number_of_earthquakes*

M : *Magnitude*

Figure 7 shows an example of Eq.1, where a-value represents the total number of seismic events with M>0, and b-value is the slope of the graph, showing the state of seismic activity. If seismic activity would change, it was thought that green line of fig.7 would move to red line or a blue one.

ICOLD stated "It has been proposed to use as diagnostic tool the b value from frequency-magnitude relations, with large b-values indicating triggered seismicity. But such use of b-value is considered controversial".
Our thought was that, if seismic activity changes before and after the impounding, then b-value will change anyway. So we considered not only b-value increases, but also b-value changes.

4.4. Seismic Activity In and Around Reservoirs

Figure 8 shows divided areas to be evaluated by b-value. These areas are chosen in order to evaluate whether the reservoir changes seismic activity around the reservoir.
Area 1 is the largest area, was chosen in order to evaluate seismic activity of whole areas.
Area 2 is where the continuous seismic events occurred near the dam, was chosen to evaluate the seismic activity varies with impounding.

Area 3 is very narrow area to evaluate near by the reservoir.

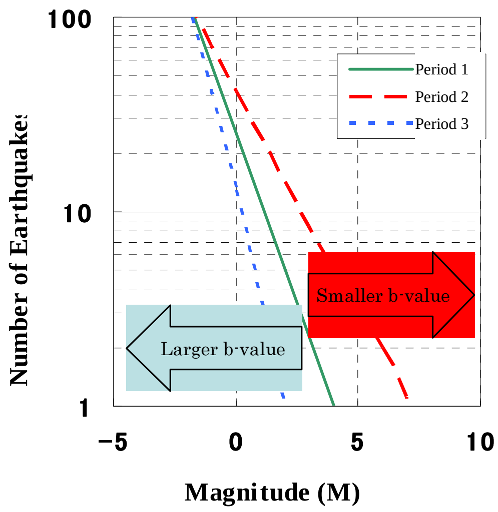

Figure 7. Example of a Gutenberg-Richter plot

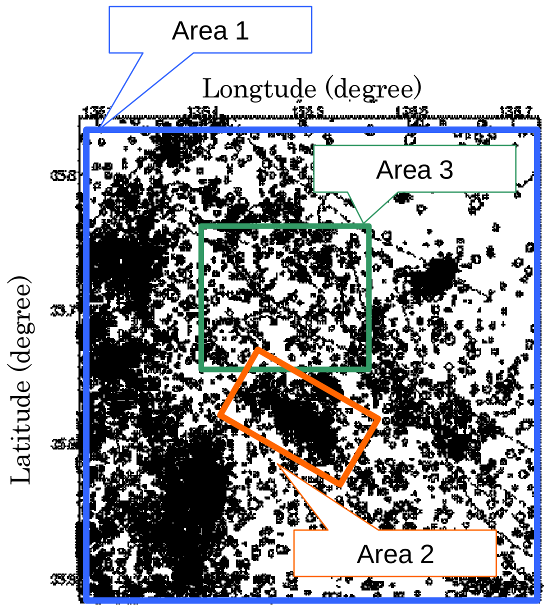

Figure 8. Areas to evaluate seismic activity

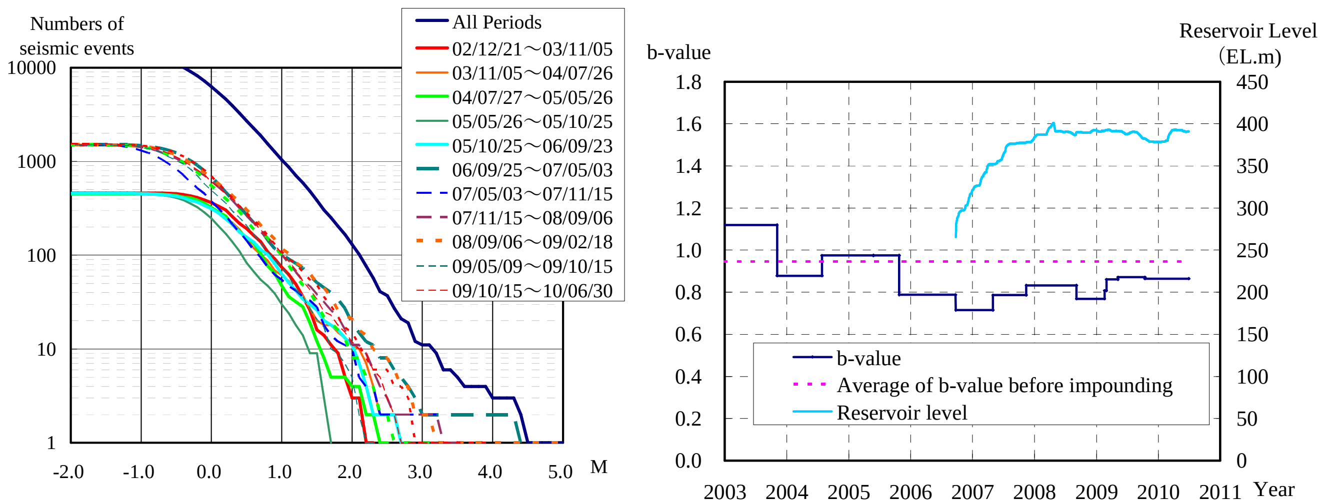

Figure 9. G-R plot and b-value changes for Area 1

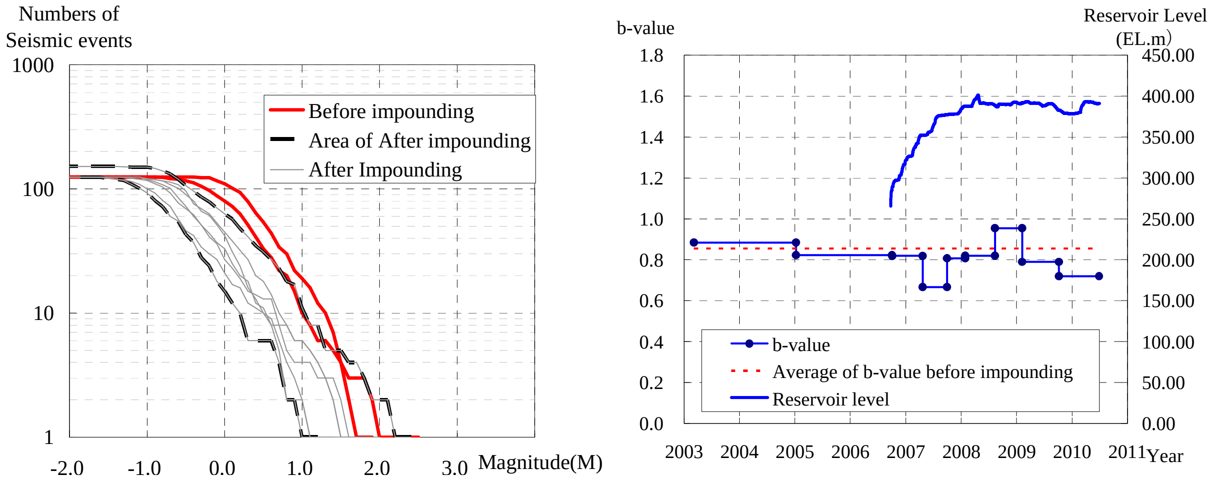

Figure 10. G-R plot and b-value changes for Area 2

The left of Figure 9 shows a relationship between frequency-magnitude for Area1. We confirmed that the b-value changes do not show any irreversible changes or extreme values. There are no major changes on the right of Fig.9, shows relationship between b-value and reservoir level.

The left of Figure 10 shows a relationship between frequency-magnitude in the Area2. We confirmed that the b-value changes do not show any irreversible changes or extreme values. There are no major changes on the right of Fig.10, shows relationship between b-value and reservoir level.

Figure 11 shows relationship between frequency-magnitude in the Area3, and relationship between b-value and reservoir level. No significant changes in b-values were observed from before to after impounding. Further, no noteworthy concentrations of hypocenters or other abnormal changes were observed from before to after impounding in or around the reservoir.

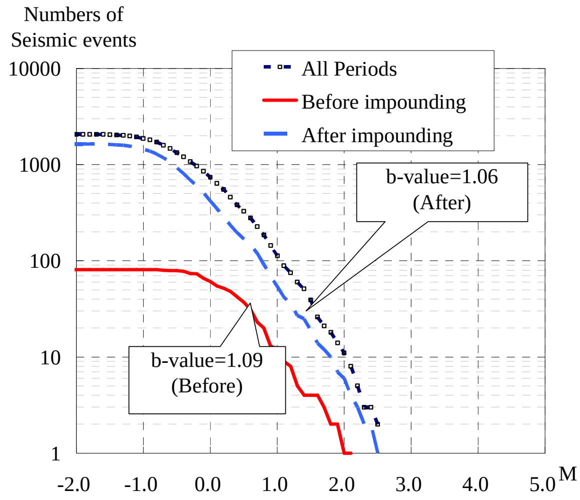

Figure 11. G-R plot and b-value changes for Area 3

Our comparisons found no significant change in relationship between neither numbers of seismic events or b-values and Reservoir level.

5. CONCLUSIONS

To understand seismic activity surrounding Tokuyama Dam, we evaluated seismic activity with JMA data and microseismic monitoring result of JWA.

JWA continue Microseismic monitoring since 1976. JWA's microseismic monitoring system enables to monitor smaller seismic events than JMA seismic records. And this paper evaluates seismic activities of recent years before and after the impounding, based on ICOLD Bulletin 137. The evaluation result was;

- Relationship between reservoir level and numbers of seismic events. There were no outstanding or trending increases in shocks along with reservoir levels, no significant changes from before to after impounding were seen seismic activity over time.
- We considered b-value changes in three of the surrounding area nearby the reservoir, no significant changes occurred in b-value.

ACKNOWLEDGEMENT

We would like to thank Professor Emeritus Ito and Associate Professor Katao of Kyoto University for their guidance from a seismological perspective

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