FEM ANALYSIS ON THE SLOW GROUND MOTION

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1. INTRODUCTION

In control of a linear collider, the ground motion is one of the big problems. Various things can be considered as a factor of the ground motion, environmental vibration, atmospheric pressure variation, and the earth tides, etc.

This time, we measured the slow ground motions using the tunnel of the underground hydroelectric power station "Shintoyone" located in the granite region.

For the following reasons, we selected Shintoyone power station as a measurement field.

a) The slow ground motion at the granite region can be measured in a tunnel.
b) The slow ground motion by operation of generators can be measured in a tunnel.
c) The slow ground motion can be measured moving a measurement position.
(Because, the length of a tunnel is enough and has reached to the ground.)
d) The slow ground motion by change of the water level of a dam can be measured.

We report the measurement results of the slow ground motion, and the examination results in FEM analysis.

2. MEASUREMENT SITE

2.1 The outline of the Tenry-river and JPOWER

Measurement of the slow ground motions was carried out on the ventilation tunnel of the Shintoyone power plant of Electric Power Development Co., Ltd. (the trading name JPOWER) located in Tenryu-river.

The origin in Tenryu-river is Lake Suwa of Nagano-Ken located in the central part of Japan. Tenryu-river, that collected the water from the Central Alps and the Southern Alps, is flowing toward south, and has reached to the Pacific Ocean, as show Fig.1.

The valley in Tenryu-river has much rainfall, and development of the electric power using the flow of rich water has been performed. JPOWER has six dams and nine hydroelectric power stations to the Tenryu-river and its branch.

That nationwide shortage of electric power should be canceled, JPOWER was established in 1952 in order to take up the development of major scale hydroelectric power generation as its initial activity. As a wholesale electric power company, JPOWER focus on developing power sources and building transmission lines, and sell electricity to Japan's 10 major electric power companies (EPCOs) through hydroelectric and coal- fired thermal power stations that they build and operate. JPOWER have stabilized supplies and enhanced efficiency by constructing a nationwide network of extra-high-voltage transmission lines for EPCOs. Furthermore, JPOWER has participated in power projects in 58 countries.

(More information about JPOWER: http://www.jpower.co.jp/english/index2.html)

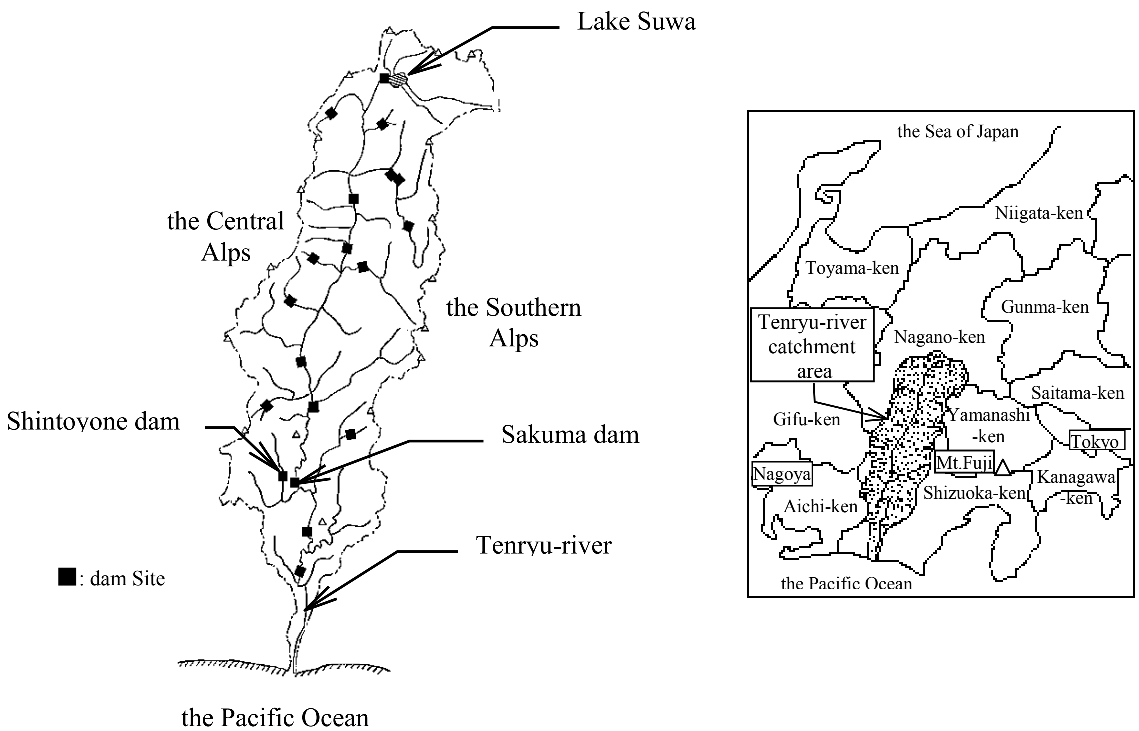

Fig. 1 Tenryu-river and dam sites

2.2 The outline of Shintoyone hydroelectric power station

Shintoyone hydroelectric power station (1,125,000kw capacity with 5 generators) is one of the largest pumped-storage power stations in Japan. That is located in 70m below ground beside the lower reservoir, and has large underground space in granite. That is space with a width of 22m, a height of 48m,and a length of 140m.

The upper reservoir (Lake Midori) is built on Shintoyone dam. (Concrete arch dam, Length=311m,Heigt=116.5m)

The lower reservoir (Sakuma storage reservoir) is built on Sakuma dam. (Concrete gravity dam, Length=293.5m,Heigt=155.5m)

Shintoyone hydroelectric power station generates using the 240m effective head of the upper reservoir and the lower reservoir.

Fig.2 shows Shintoyone dam, and Fig.3 shows Sakuma dam.

Fig. 2 Shintoyone dam Fig. 3 Sakuma dam

2.3 Measuring points and devices

Shintoyone hydroelectric power station has some utility tunnels. The ventilation tunnel (length=260m) leads from underground plant to the ground.

We installed a set of half filled water tube tiltmeter in the place near the generators which is 70m below ground in a ventilation tunnel as shown in Fig.4.

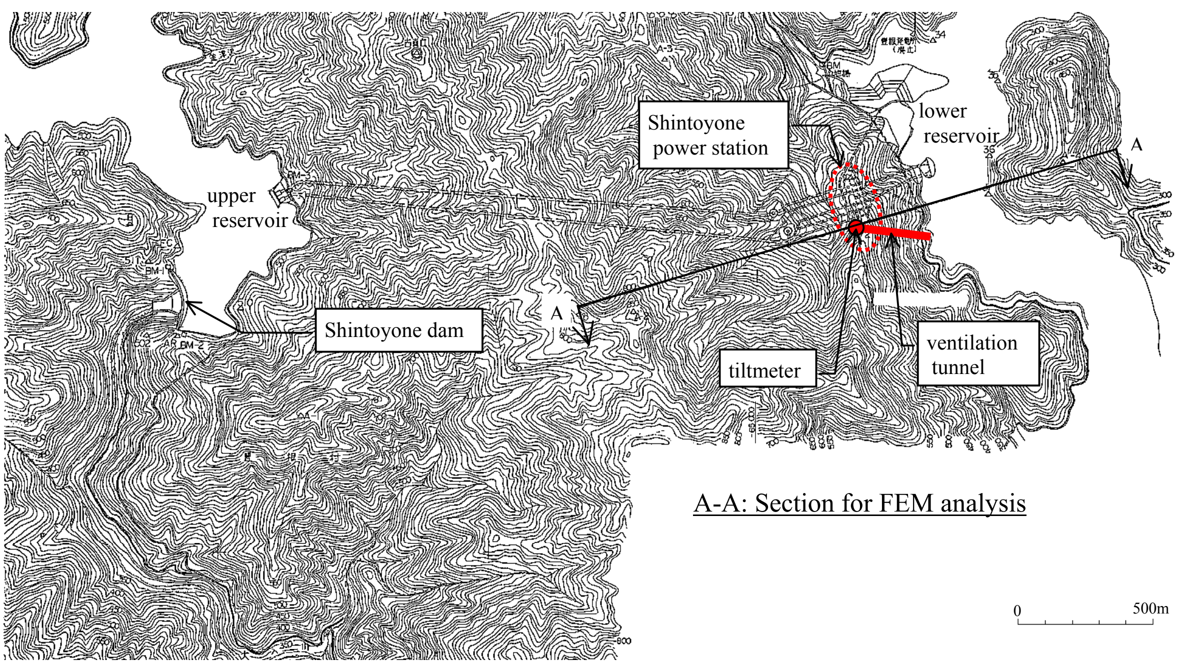

Fig. 4 Shintoyone hydroelectric power station plane

In order to reduce change of the temperature in a ventilation tunnel, we covered the tiltmeter with styrene foam from the middle of a measurement period. We also installed force balance broadband seismometer meters and bubble level tiltmeters in the ventilation tunnel. See reference [1] to get more information about measuring instruments.

In this report, we examine the data of half filled water tube tiltmeter, and an installation situation photograph is shown in Fig.5.

Fig. 5 A set of half filled water tube tiltmeter in the ventilation tunnel

3. MEASUREMENT RESULT

The result of measurement is shown in Fig.6.

We changed the measured data of sampling interval 10sec to the average value for 10 minutes. Moreover, the water level data of the lower reservoir is data of AM9: 00 every day.

The red line shows tilt observed by half filled water tube tiltmeter. The blue line shows change of the water level of the lower reservoir. When tilt will become large if the water level of the lower reservoir becomes low, and the water level of a lower pond becomes high, it turns out that tilt becomes small.

The above thing shows that the tendency of change of the water level of a lower reservoir and the tendency of change of the slow ground motion are well in agreement. However, the size of change with the water level of a lower reservoir and tilt is not necessarily in agreement.

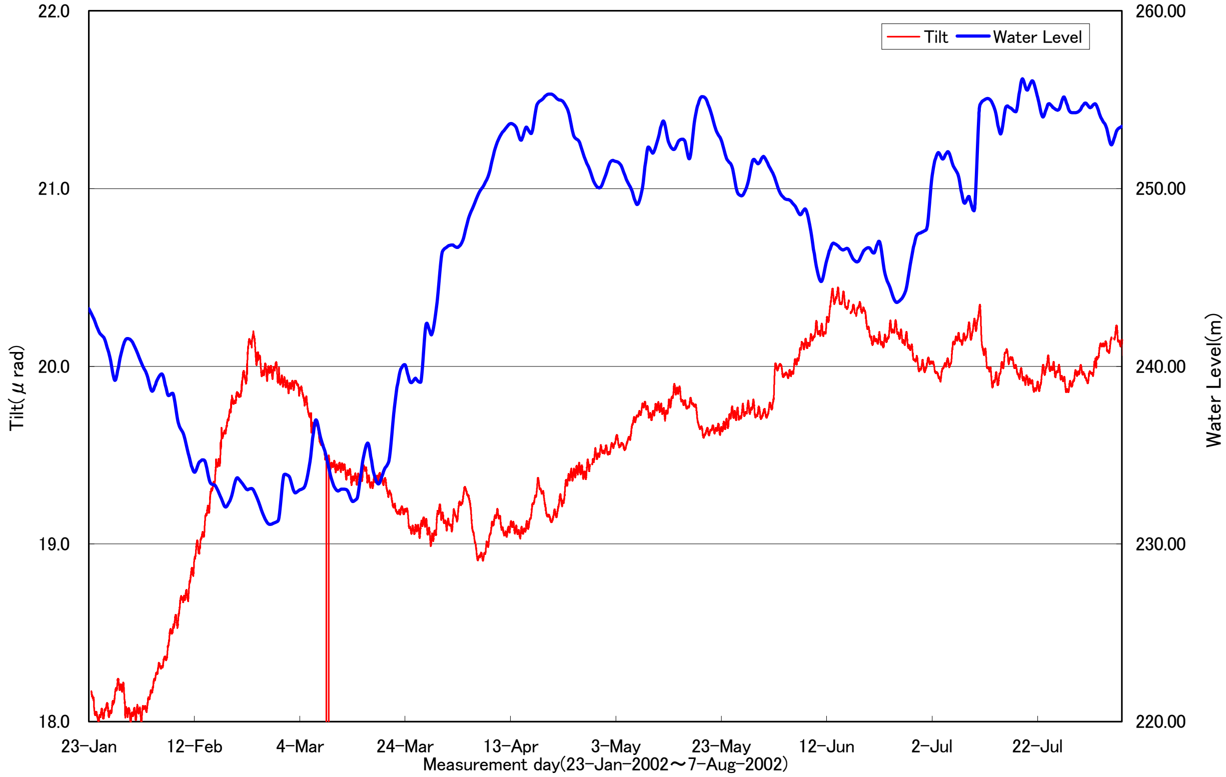

Fig. 6 Tilts and water level of the lower reservoir

4. THE RESULT OF FEM ANALYSIS

4.1 Analysis model

We carried out 2-dimensional FEM (Finite Element Method) analysis, for considering the relation between change of the water level of the lower reservoir and the slow ground motion. FEM analysis model is shown in Fig.7. (Section A-A in Fig.4.)The analysis range set up about 2,000m width including the measurement point. We considered all as uniform granite zone without setting a stratum boundary. On bottom and both sides of FEM analysis model, boundary conditions are as follows.

Bottom: Vertical: fixation, Horizontal: fixation
Side : Vertical: slide, Horizontal: fixation

4.2 Properties

We analyzed by changing the elastic modulus of granite to the following two cases.

Case1: The elastic modulus as test piece. (Non cracks)
Case2: The elastic modulus as rock mass. (Including cracks)

Density and Poisson's ratio used the general value. The properties are shown in Table 1,and we inputted the effect of the water level as load.

The conditions of the water level of the lower reservoir are as follows.

High water level (HWL)=+243m

Low water level (LWL)=+231m

The examination period was made into the beginning of March from the measurement start. The determination of the period is because dam operation of reducing the water level gradually was carried out by JPOWER.

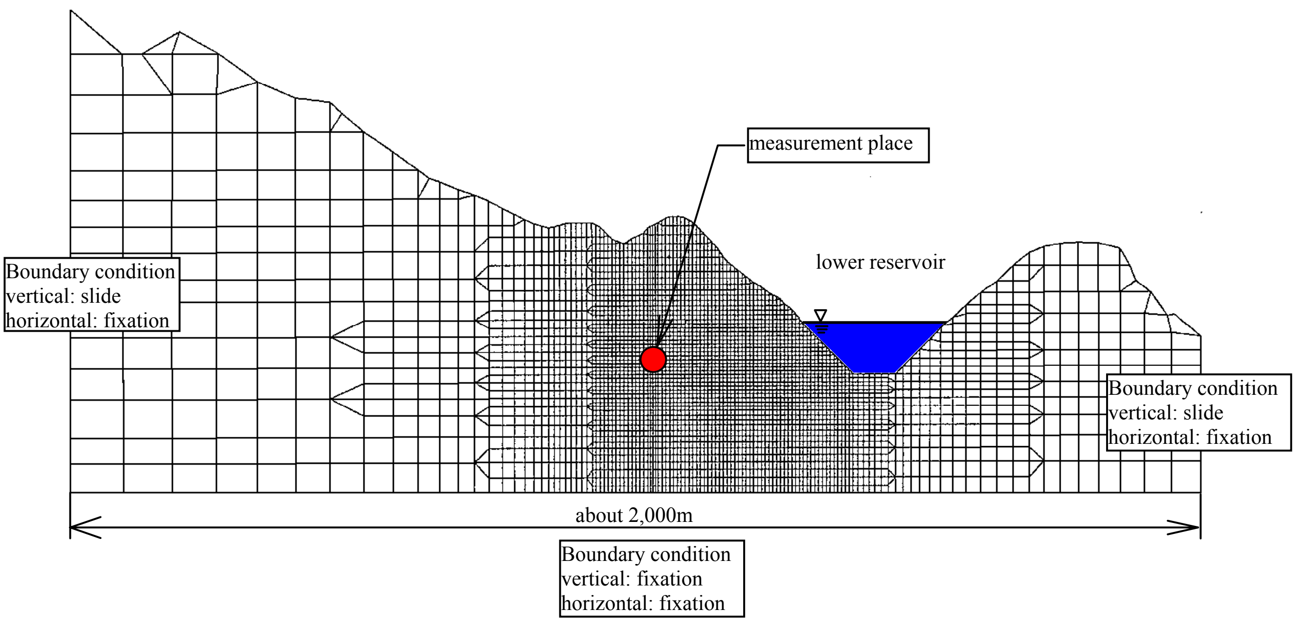

Fig. 7 FEM analysis model (FEM mesh for analysis)

Table1 Properties

	Case1	Case2
Density	2.65g/cm^3	2.65g/cm^3
Elastic modulus	51,000kN/cm^2 *1(520,000kg/cm^2)	5,100kN/cm^2 *2(52,000kg/cm^2)
Poisson's ratio	0.20	0.20

*1:Typical value of granite as test piece (Non cracks)
*2:Typical value of granite as rock mass (Including cracks)

4.3 Analysis result

The displacement in node is outputted from the result of FEM analysis.We created the FEM model so that the solution of the displacement of the 19m away node could be carried out.This is because the length of the water tube of tiltmeter is 19m.

Therefore, the calculated displacement is changed into the tilt using the following formula.

$$\text{Tilt } (\mu rad) = (Dby - Day)/(Dbx - Dax + 19{,}000{,}000) \qquad (1)$$

Dax: Horizontal Displacement at node A. (μm)
Day: Vertical Displacement at node A. (μm)
Dbx: Horizontal Displacement at node B. (μm)
Dby: Vertical Displacement at node B. (μm)
(Refer to Fig.8.)

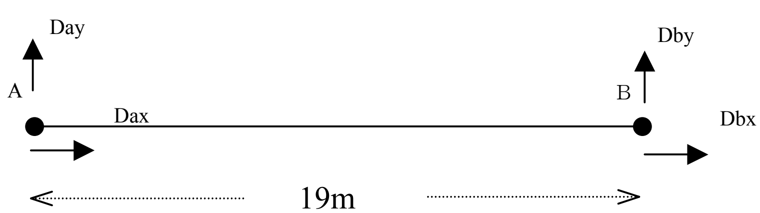

Fig. 8 Description of the formula (1)

Even if it compares an analysis result with a measurement value, it does not suit well. This is because a measurement value includes the effect of various factors, such as the earth tide, to analysis including only the effect of a water level. So, we decided to use a difference at the time of HWL, and at the time of LWL, as show in Table2.

Table2 Result of analysis

	Analysis		Tiltmeter measurement (μrad)
	Case1 (μrad)	Case2 (μrad)	
Difference of the tilt between HWL and LWL	0.11	1.05	2.10

By reference, an example of an analysis output is shown in Fig. 9&Fig.10. Those show vertical displacement by the contour. According to the figures, the difference of the water level of the lower receiver is calculated as a difference of vertical displacement.

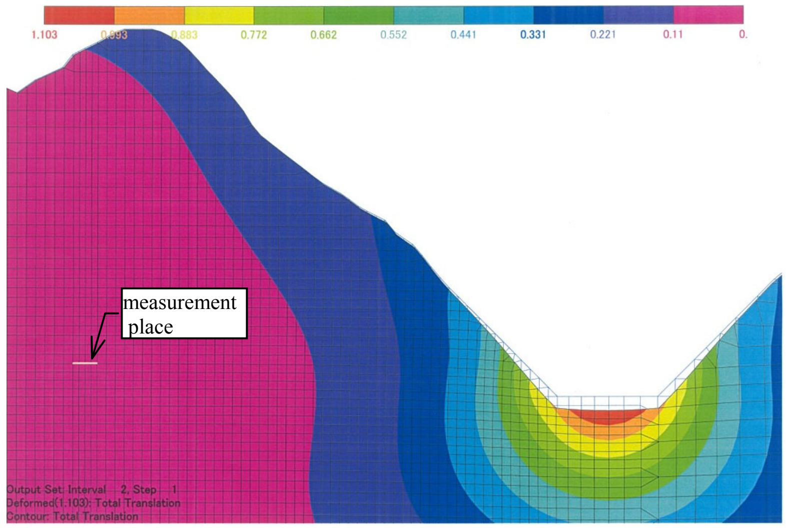

Fig. 9 Example of output, vertical displacement by the contour in LWL, Case2

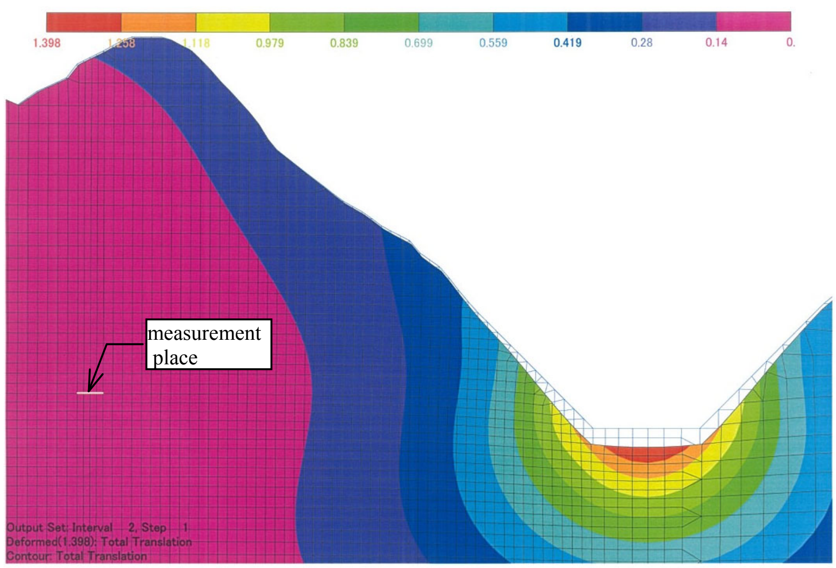

Fig. 10 Example of output, vertical displacement by the contour in HWL, Case2

4.4 Conclusion

In measurement result, the difference of the tilt between the case of HWL and the case of LWL is 2.1μrad. That difference is 0.11μrad in Case1, and becomes a small value as compared with the measurement result. The reason why that result is the elastic modulus used by

Case1.The elastic modulus used by Case1 is a value in the state of test piece without cracks. As compared with what exists in the rock mass, it is larger.

On the other hand, the elastic modulus used by Case2 is a value in the state in the rock mass including cracks, and the calculated result is 1.05 μrad. This is mostly in agreement with the measurement result.

As mentioned above, measurement and analysis are well in agreement.

5. A FUTURE SUBJECTS

In these measurement and analyses, the influence change of the water level of dam affects the slow ground motion became clear.

We were able to acquire the precious knowledge towards examination of linear colliders. The future examination subjects are as follows.

1. Study of the grade which vibration in earth surface decreases toward the depth.
2. Study of the relation between the difference in the kind of rocks and the ground motion.

So, we are planning another measurements to the above-mentioned examination subjects at the ventilation tunnel in Shintoyone and at another fields.

6. REFERENCES

[1] Takeda et al., *Ground Motion Studies near the Dam Site*, 8th European Particle Accelerator Conference (EPAC2002), Paris, 3-7 June 2002: KEK Preprint 2002-51A, June 2002.