PROC. OF JSCE,
No. 240, AUG. 1975

DYNAMIC PROPERTIES OF THE AINONO EARTH DAM AND THE USHINO ROCK-FILL DAM

By *Yoshinobu* MORI* *and* *Fusayoshi* KAWAKAMI**

1. INTRODUCTION

The importance of earthquake loads which should be considered in design of fill-type dams has been enhanced recently when a number of fill-type dams are being constructed. In order to construct a large earth and rock-fill dam in our country where great earthquake frequently occurs, it is necessary that the behaviour of the dam suffered from earthquake shock is investigated in detail.

Many analytical studies have been carried out on the earthquake response of fill-type dams by the finite element method or the finite difference method with the progress of electronic computers, but in order to judge the appropriateness of the results of these analysis, the results should be compared with the earthquake response observed on the actual dams. Therefore, the observations of earthquakes on the actual dams are basic matter to develop the reasonable method of aseismic design of such dams.

This paper deals with the results of the observations of earthquakes on the actual dams.

2. THE EARTHQUAKE RESPONSE OF FILL-TYPE DAMS OBSERVED ON THE ACTUAL DAMS

The observations of earthquakes and the analysis were carried out for two dams, one of which is the Ainono earth dam (40.8 m in height), and the other is the Ushino rock-fill dam (21.4 m in height). Besides, the results observed on other several dams were referred[1),2)].

The Ainono Dam, one of the high earth dams in Japan, completed in 1961, has been used as a reservoir for irrigation. The materials of dam are composed of 28 per cent sand, 40 per cent silt, and 32 per cent clay by weight. The values of the unit dry weight, the cohesion, and the angle of internal friction are about 1.17 t/m^3, 1.30 $\sim$1.40 kg/cm^2, and 13$\sim$20 degrees respectively. The outline of the dam is given in Fig. 1. It has a maximum height of 40.8 m and crest length of 132.9 m, and is a homogeneous embankment type with an inserted drainage filter. The stratum at the dam base is formed of hard shale. Six transducers of acceleration device were buried near the surface of dam and dam base, as shown in Fig. 1. All the transducers are used for recording horizontal accelerations normal to the dam axis.

The Ushino Dam is a rock-fill dam for irrigation, and was completed in 1968. For the material of rock-fill, a tuff was used. The typical values of the unit dry weight, the cohesion, and the angle of internal friction are 1.68 t/m^3, 0.33 kg/cm^2, 46.5 degrees respectively in the rock-fill material, and 1.72 t/m^3, 0.68 kg/cm^2, and 11.5 degrees respectively in the clay core material. The outline of the dam is given in Fig. 2. It has a maximum height of 21.4 m and crest length of 160 m, and has an inclined core wall. The stratum of dam base is formed of tuff. Five transducers of acceleration device were buried near the surface of dam and base, as shown in Fig. 2. All the transducers are used for recording horizontal accelerations normal to the dam axis.

Block diagram of the installation is shown in Fig. 3. The acceleration of earthquakes is converted into electric signals by transducers, attenuated and recorded on an electromagnetic oscillograph. The recording device begins to run by working of the automatic starter when a seismic shock of a certain intensity is felt. Table 1 shows the characteristics of the instruments.

(1) Vibration of Dam Base

Table 2 shows the location of epicenters and

* Dr. Eng., Assistant Professor of Civil Engineering, Nihon University.
** Dr. Eng., Professor of Civil Engineering, Tohoku University.

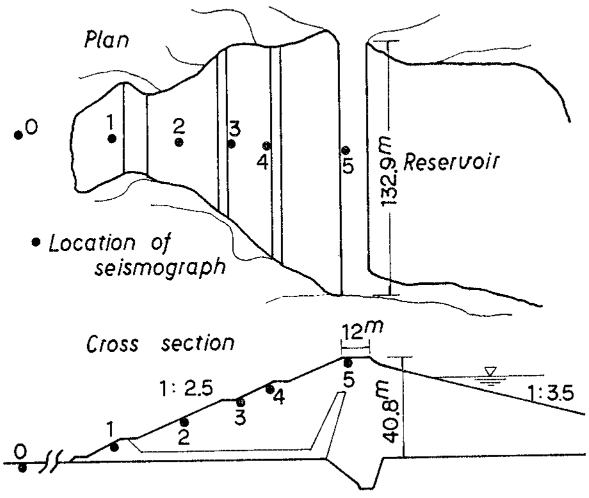

Fig. 1 Ainono Dam.

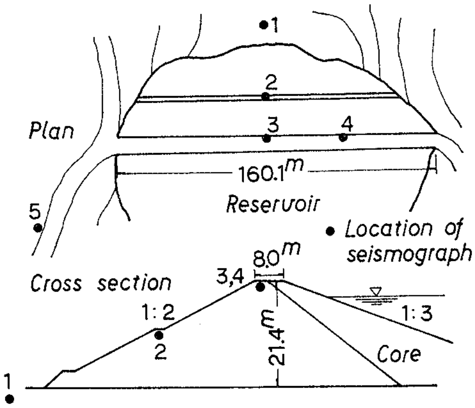

Fig. 2 Ushino Dam.

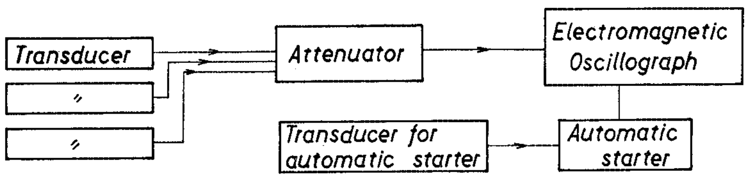

Fig. 3 Block diagram of installation.

Table 1 Characteristics of instruments.

Transducer of acceleration device	natural frequency	3 c. p. s.
	critical damping	40
	damping factor (h)	11
	sensitivity	15 μA/gal
	measurable maximum acceleration	200 gal
Electromagnetic oscillograph	natural frequency of galvanometer	500 c. p. s.
Automatic starter	min. workable input	22 mV
	min. workable sensitivity	0.005 cm/sec

Table 2 List of earthquakes observed at Ainono Dam.

No.	Date	Epicenter E	Epicenter N	Depth	Magnitude
A3	1968. 5.16	143°42′	40°42′	20 km	7.8
A4	5.22	142 48	41 30	40	5.9
A5	6.14	142 48	39 18	37	4.5
A8	10.27	145 43	42 48	60	5.2
A9	11.4	144 05	40 12	0	5.0
A10	12.18	144 09	40 17	0	4.9

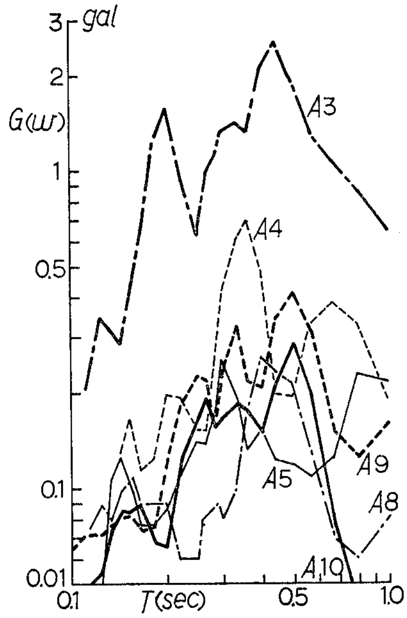

Fig. 4 Acceleration spectra of seismic waves at the base of Ainono Dam.

Table 3 List of earthquakes observed at Ushino Dam.

No.	Date	Epicenter		Depth	Magnitude
		E	N		
U2	1969. 1.19	143°29′	44°33′	260 km	
U4	2.17	141 02	37 27	80	
U5	3.17	142 59	38 32	70	
U7	6.11	142 00	38 32	40	4.5
U8	6.20	142 12	38 25	60	6.2
U9	6.23	141 40	37 18	50	5.2

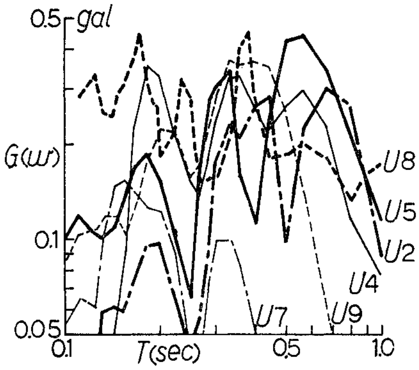

Fig. 5 Acceleration spectra of seismic waves at the base of Ushino Dam.

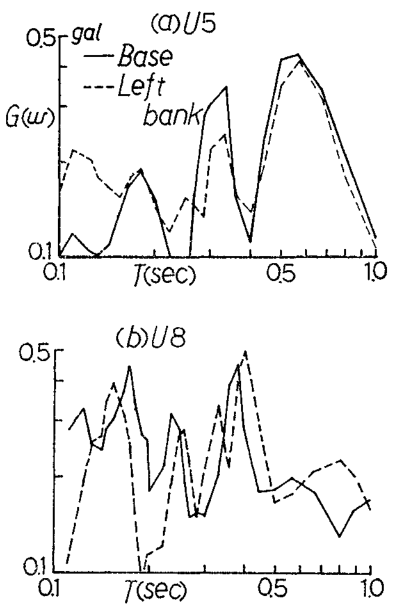

Fig. 6 Comparisons of the acceleration spectra.

the depth of hypocenters which were observed at the Ainono Dam. Fig. 4 shows the acceleration spectra (Fourier spectra) of seismic waves at the base of the Ainono Dam. The predominant period of about 0.15 sec and 0.30~0.35 sec can be found commonly for every earthquake[3]. These predominant periods are considered to be due to the natural vibrational characteristics of the dam base. Earthquake No. A 9 and A 10 have approximately almost the same epicenter, and the acceleration spectra of both seismic waves resemble closely. This means that the seismic waves are influenced by the route in which waves propagate.

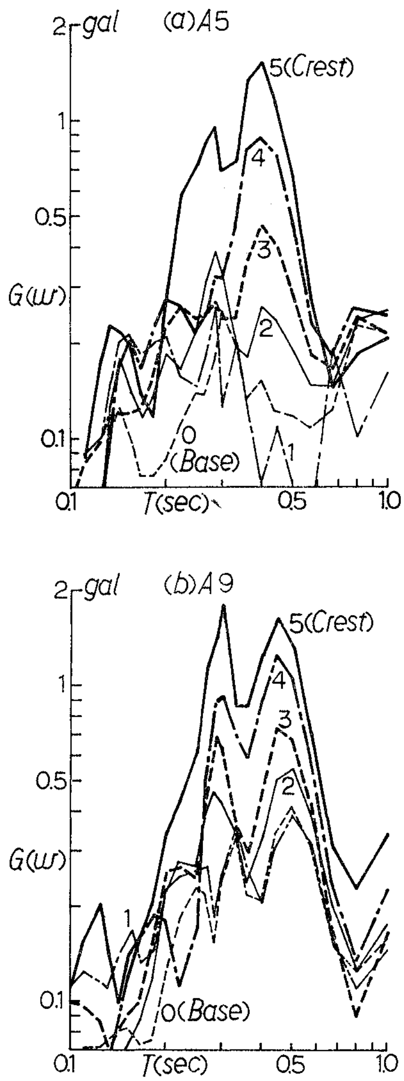

Fig. 7 Acceleration spectra (Ainono Dam).

Table 3 shows the location of epicenters and the depth of hypocenters which were observed at the Ushino Dam. Fig. 5 shows the acceleration spectra of seismic waves at the base of the Ushino Dam. There are the predominant periods of about 0.18 sec and about 0.35 sec commonly for every earthquake. There is no significant difference between the acceleration spectra of seismic waves observed at the base (No. 1 transducer) and those at the left bank (No. 5 transducer) as shown in Fig. 6.

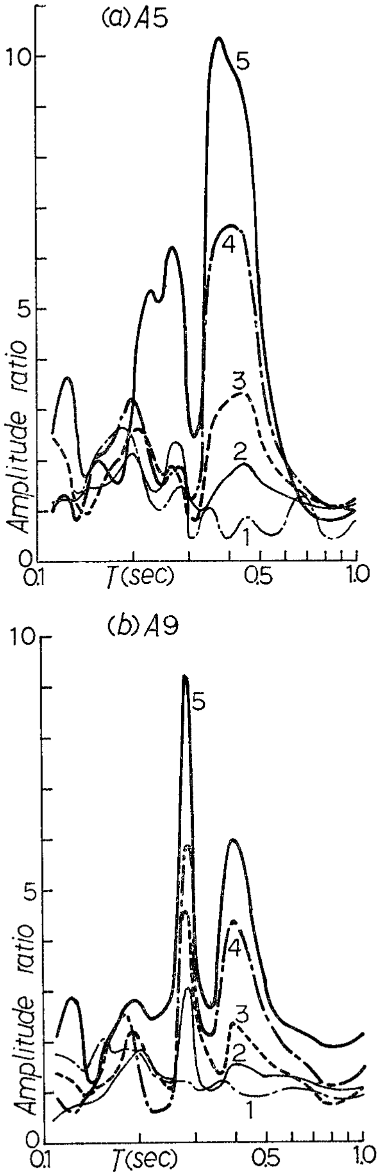

Fig. 8 Amplitude ratio (Ainono Dam).

(2) Vibrational Behaviour of Dam Body

Some examples of the acceleration spectra of the seismic waves which were recorded at the Ainono Dam are shown in Fig. 7. The predominant period of dam given by these acceleration spectra is about 0.4 second. Some examples of the amplitude ratios of the spectra obtained at the crest and the downstream slope to the spectrum obtained at the base are shown in Fig. 8. Two predominant periods, 0.40~0.45 sec and about 0.25 sec, are recognized commonly for every earthquake in Fig. 8. The periods of 0.40~0.45 sec and about 0.25 sec may be the first modal period and the second modal period of the Ainono Dam, respectively.

Fig. 9 shows some examples of the acceleration spectra of seismic waves which were recorded at the Ushino Dam. Fig. 10 shows the amplitude

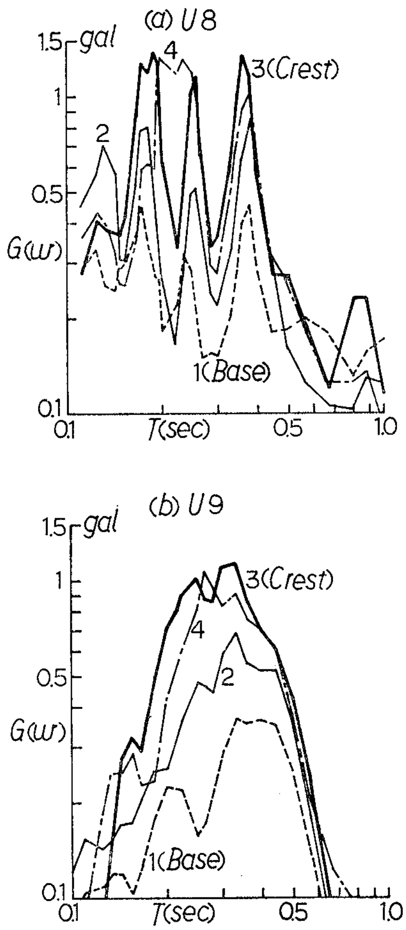

Fig. 9 Acceleration spectra (Ushino Dam).

ratio of the spectra obtained at the crest and the middle point of the downstream slope to the spectrum obtained at the base. From these figures, it may be found that the first modal period and the second modal period of the Ushino Dam are 0.26 sec and about 0.15 sec, respectively.

The amplitude ratios in Fig. 8 and Fig. 10 vary with the intensity of every earthquake. Fig. 11 shows the relation between the amplitude ratio of the acceleration spectra at the crest to those

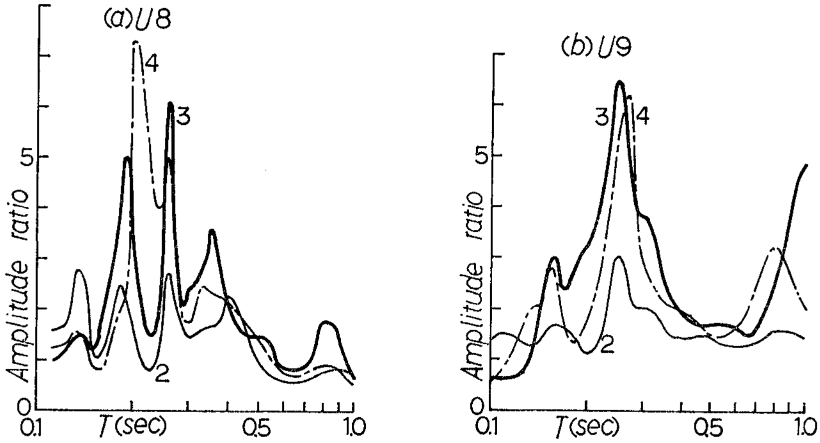

Fig. 10 Amplitude ratio (Ushino Dam).

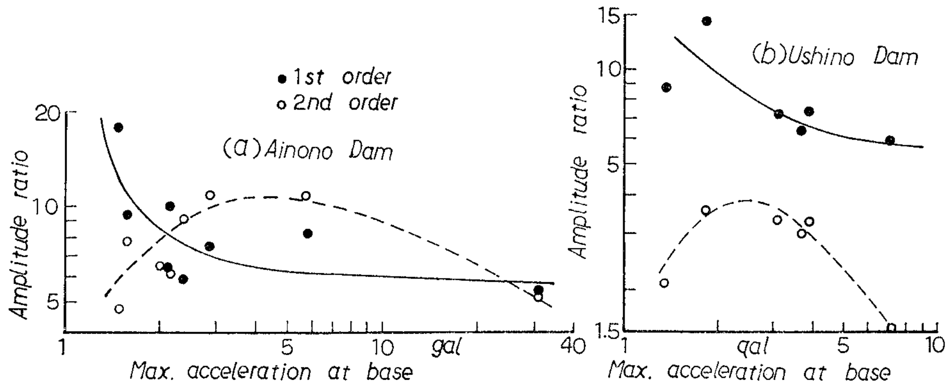

Fig. 11 Relation between the amplitude ratio and the maximum acceleration at the base.

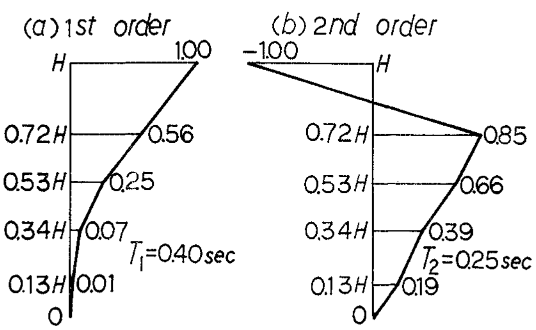

Fig. 12 Amplitude distribution on the slope of Ainono Dam.

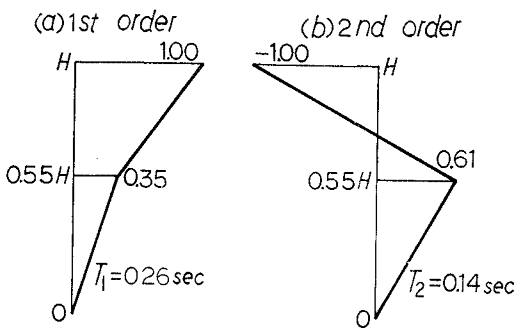

Fig. 13 Amplitude distribution on the slope of Ushino Dam.

at the base for the first and second modal period, and the maximum accelerelation at the base. The amplitude ratios for the first modal period are larger in case of a weaker earthquake, and reduced to a certain value (5~6 times) when the earthquakes are stronger. On the other hand, the amplitude ratios for the second modal period have a maximum when the maximum accelerations at the base are 2~4 gal, and decrease as the accelerations increase. This means that the magnifications for the second modal period are not very important for the massive structures such as fill-type dam.

Fig. 12 and Fig. 13 show the amplitude distributions on the downstream slope of the Ainono

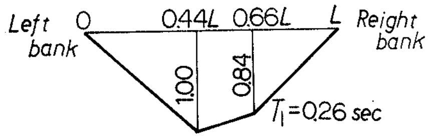

Fig. 14 Amplitude distribution along the crest of Ushino Dam.

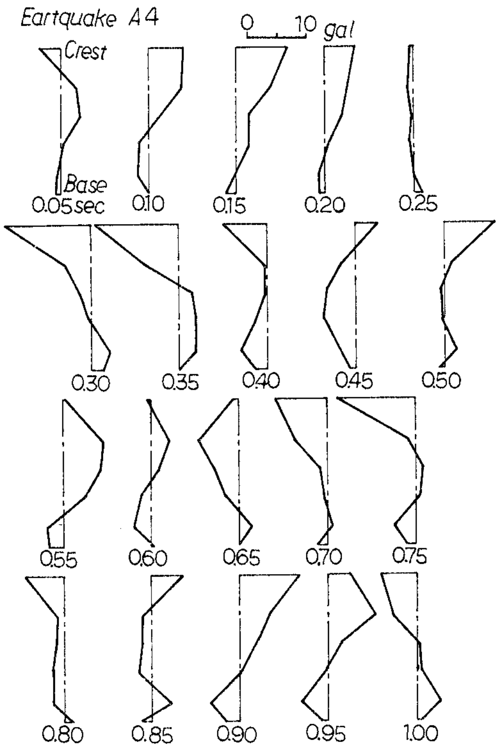

Fig. 15 Time history of the distribution of seismic accelerations on the slope of Ainono Dam.

Dam and the Ushino Dam respectively, and Fig. 14 shows the amplitude distribution along the crest of the Ushino Dam. From these figures, it is considered that the dam quakes largely in the upper one third part of dam height.

Fig. 15 shows the time history of the distribution of seismic accelerations on the slope of the Ainono Dam. In this figure, the phase differences are recognized between upper and lower parts of the dam.

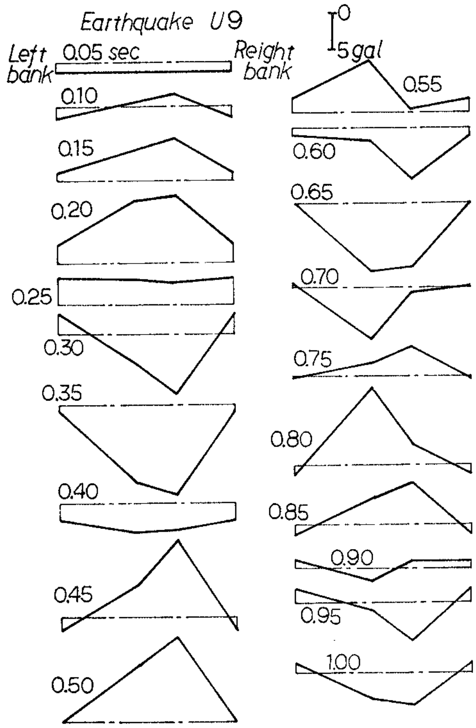

Fig. 16 Time history of the distribution of seismic accelerations along the crest of Ushino Dam.

Fig. 16 shows the time history of the distribution of seismic accelerations along the crest of the Ushino Dam. In this case, there are also the phase differences between the center of the crest and near the abutments.

Fig. 17 shows the relation between the maximum acceleration at the dam crest and that at the base[4),5)]. As shown in this figure, the acceleration at the crest becomes larger with the maximum acceleration propagated to the foundation, but the rate of the amplification decreases. That is, the damping effect increases with the intensity of vibration. The rate of the amplification differs also due to the height of the dam.

However, it may be considered that the maximum acceleration at the dam crest shows a value approximately two times for the strong earthquakes as that at the base.

Fig. 18 shows the autocorrelation coefficient of the seismic waves observed at the base, the downstream slope and the crest of the Ushino Dam.

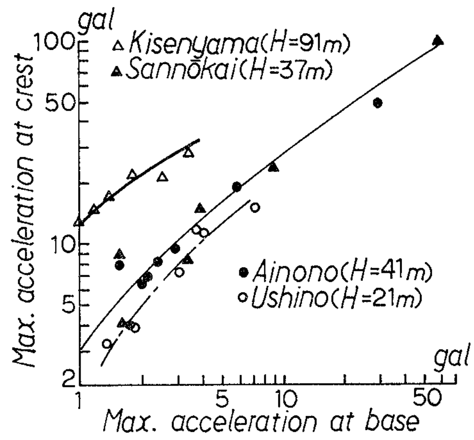

Fig. 17 Relation between the maximum acceleration at the crest and ones at the base.

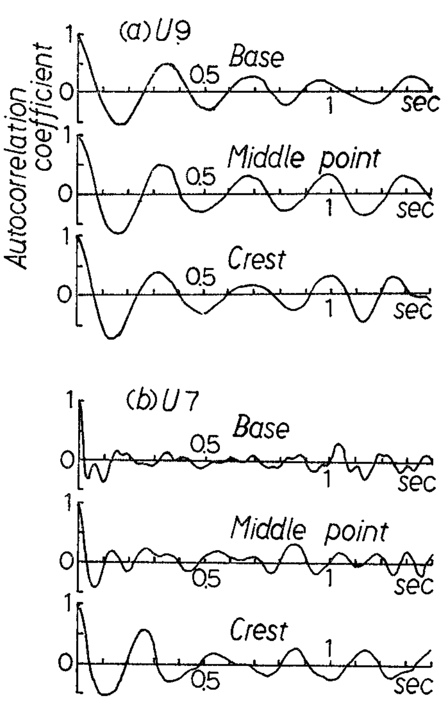

Fig. 18 Autocorrelation coefficient.

The seismic wave of the earthquake No. U9 has periodic property, and its predominant period is about 0.35 second. In this case, the dam quakes periodically with almost the same period as at the dam base, but the predominant period shifts toward the natural period of the dam body with the height, and the predominant period at the crest is about 0.30 second. On the other hand, the seismic wave of the earthquake No. U7 has specially irregular property. In this case, the dam quakes predominantly with the natural period of the dam, and the predominant period at the crest is 0.26 second.

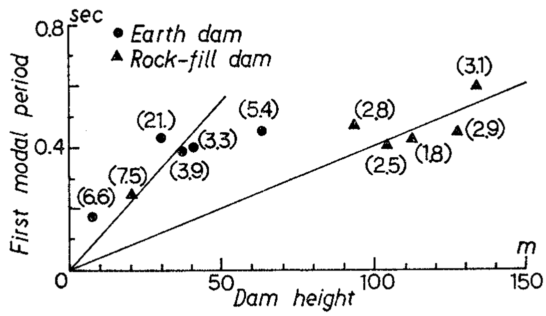

Fig. 19 Relation between the dam height and the first modal period.

Fig. 19 shows the relation between the dam height and the first modal periods of dam obtained from the earthquake observations[6]. The first modal periods are not directly proportional to the dam heights. The chief reasons are probably the effects of the restraint by the valley and the change of the modulus of rigidity with the dam height. In Fig. 19, the numerical values in the parentheses indicate the ratio of the crest length to the dam height, and two straight lines illustrate graphically Eq. (1) obtained empirically by Okamoto[6].

$$\left.\begin{array}{ll}\text{Earth dam} & T=0.011H \\ \text{Rock-fill dam} & T=0.004H\end{array}\right\} \cdots\cdots\cdots\cdots(1)$$

where T: first modal period (sec)

H: dam height (m)

In case of which a crest length-to-height ratio is large, it seems that the first modal period has a larger value than a value gained from Eq. (1).

Table 4 shows the damping factor in the first order obtained from the earthquake observations. These damping factors are larger compared with other type structures such as concrete buildings and bridges.

It is estimated from the cross correlation function between the seismic waves observed at the

Table 4 Damping factor.

Ainono Dam		Ushino Dam	
Earthquake No.	Damping factor	Earthquake No.	Damping factor
A 3	0.096	U2	0.110
A 4	0.079	U4	0.082
A 5	0.156	U5	0.056
A 6	0.139	U7	0.062
A 7	0.099	U8	0.035
A 8	0.136	U9	0.090
A 9	0.122	Mean	0.073
A10	—		
Mean	0.118		

base and those at the crest that the velocities of shear wave propagation in the dam body are 240 ~360 m/sec in the Ainono Dam, and 310~410 m/sec in the Ushino Dam respectively.

3. CONCLUSION

The main conclusions drawn from the preceding pages may be summarized as follow:

(1) The acceleration spectra for the first modal period at the crest are amplified larger in case of weaker earthquake, and the amplification degree reduces to a certain value when the earthquake are stronger. On the other hand, the amplification degree for the second modal period at the crest has a maximum when the maximum accelerations at the base are 2~4 gal, and decreases as the accelerations at the base increase.

(2) When the characteristic of input waves is quite periodic, the dams quake periodically with almost the same period as at the dam base, but, the frequency which the dams can follow may be restricted to a certain range. When the ground shakes at random, the dams quake predominantly with the natural period of dams.

(3) The acceleration at the crest becomes larger with the maximum acceleration propagated to the foundation, but the rate of amplification decreases. That is, the damping effect increases with the intensity of vibration. The rate of amplification differs also due to the height of a dam. However, it may be considered that the maximum acceleration at the dam crest shows a value approximately two times for the strong earthquakes as that at the base.

(4) The dam quakes largely in the upper one third part of dam height.

(5) The first modal periods are not directly proportional to the dam heights. But it seems that there exists some relation between the first modal period and the dam height.

(6) The damping factors in the first order are about 0.12 for the Ainono Dam, and about 0.07 for the Ushino Dam respectively.

REFERENCES

1) Okamoto, S., Hakuno, M., Kato, K. and Kawakami, F.: Proc. of Third World Conference of Earthquake Engineering, Vol. 2, pp. 458~467, 1966.
2) Kawakami, F., Asada, A. and Mori, Y.: Response Characteristics of Earth Dams during Earthquake, Proc. of the Third Japan Earthquake Engineering Symposium, pp. 453~460, 1970 (in Japanese).
3) Mori, Y. and Kawakami, F.: Earthquake Response of Fill-type Dams, The Technology Reports of the Tohoku University, Vol. 38, No. 1, pp. 37~65, 1973.
4) Okamoto, S., Tamura, C., Kato, K. and Otawa, M.: Dynamic Beoavior of Earth Dam during Earthquakes, Report of the Institute of Industrial Science, The University of Tokyo, Vol. 16, No. 4, pp. 1~57, 1966.
5) Kansai electric power company: The Report of the Observation on the Kisenyama Rockfill Dam, 1969 (in Japanese).
6) Okamoto, S. and Tamura, C.: Stability of Rock-fill Dams, The text-book for the lecture and the forum on the engineering of dam construction, pp. 1~19, 1970 (in Japanese).

(*Received Nov. 11, 1974*)