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12. *Some New Problems of Seismic Vibrations of a Structure. Part 2. (Case of a Dam).*

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Abstract

The idea of the multiple reflection problem of waves in an elastic layer is applied to the problem of seismic vibration of a dam. It was found that the agreement of the observational result and the theoretical one in each actual dam is well beyond expectation.

In general, the amplitudes of vibration at the top of the actual dams become relatively large and take naturally a decaying type. This is due to the energy dissipated outwards through the neighbouring medium, the problem being now of wave propagation and not of pure stationary vibration with energy condensed in a conservative system.

1. Introduction

From the results of the previous investigation,[1] we knew that the vibration of a building due to earthquake motions should be treated as the multiple reflection phenomena of waves. The results also told us that the most important part of the vibrational damping of a building is based on that at the time of an earthquake, the vibration energy of a building dissipating into the ground again as in a wide sense the elastic waves which start from the foundation.

In the present paper, the problem of vibration of a dam due to seismic waves will be investigated making a comparison between the theoretical results of the multiple reflection problem of waves in the actual dams and the observational result of earthquake motions in each one.

1) K. KANAI and S. YOSHIZAWA, "Some New Problems of Seismic Vibrations of a Structure. Part 1," *Bull. Earthq. Res. Inst.*, **41** (1963), 825-833.

2. Comparison of the theoretical and the observational results

The actual dams treated in the present investigation are the Tsukabaru dam of gravity type and the Kamishiiba dam and Sazanamigawa dam of arch type.

The locations and the constants of these dams are represented in Fig. 1 and Table 1, respectively. In Table 1, the values of frequency and damping ratio have been obtained by the vibration test using a vibration generator.[2] The constants and the positions of the horizontal seismographs installed at the dams are represented in Table 2 and Figs. 2–4, respectively. The data of the earthquakes used in the present investigation is listed in Table 3.

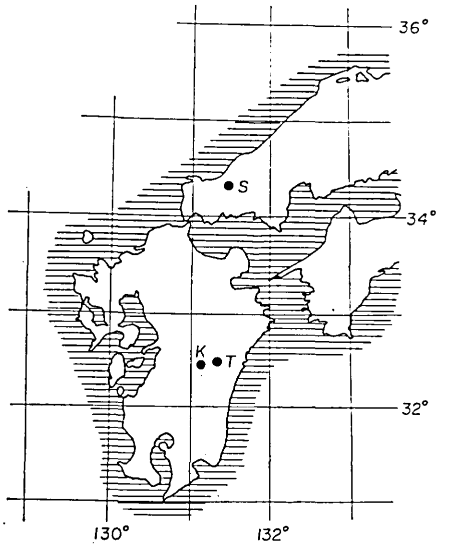

Fig. 1. Location of the dams. T: Tsukabaru dam, K: Kamishiiba dam, S: Sazanamigawa dam.

If the assumptions are made that the reflection coefficients of waves at the free surface, $z=H$, and the lower boundary, $z=0$, in a dam are 1 and β, respectively, and the attenuation of waves in that dam is negligibly small, the vibrational damping of it depends mostly on the boundary condition between the dam and the ground, that is, β.

One of the results of the theoretical study based on the idea of the multiple reflection problem of waves in an elastic layer, that is, equation (1) may be applicable in the present problem.

$$u_{z=0}\left(t-\frac{H}{V}\right)=\frac{1}{2}\left\{u_{z=H}(\tau)+u_{z=H}\left(\tau-\frac{2H}{V}\right)\right\} \qquad (1)$$

In equation (1) $\tau=t-H/V$ and $\tau=0$ and $t=0$ correspond to the arrival time of waves at $z=H$ and $z=0$, respectively, and V the apparent transmission velocity of waves in that dam.

Equation (1) tells us that if only we know the value of $2H/V$ in a

2) T. TAKAHASHI, "Vibration of the Concrete Dams," *Rep. 5th Meeting, Central Res. Inst., Electric Power Industry*, Nov., 1963, 111–114, (in Japanese).

Table 1. Constants of the dams.

Name	Height (m)	Mode		Water level			
				Full		Low	
				Frequency (c. p. m.)	Damping (%)	Frequency (c. p. m.)	Damping (%)
T dam	78	Sym.	1st	415	12		
K dam	110	Sym.	1st	230	5		
			2nd	350	4	380	4
			3rd	520	4.5	580	4.5
		Anti-	1st	260	4	280	4
			2nd	430	4.5	480	4
S dam	67	Sym.	1st	330	2	400	1.5
			2nd	410	3.7		
		Anti-	1st	260	3	330	1.8
			2nd	520	2		

T; Tsukabaru, K; Kamishiiba, S; Sazanamigawa, Sym.; Symmetric, Anti-; Anti-symmetric.

Table 2. Constants of the seismographs.

Name	Natural period (sec)	Damping (%)	Magnification
T dam	1.0	60	1,000
K dam	1.0	60	1,000
S dam	1.0	60	400

Orientation of the seismographs is parallel to each river.

Table 3. Data of the earthquakes.

Name	Date	Origin	Remark
T dam	Apr. 27, 1960		
K dam	Feb. 10, 1960	about 30°N, 130°E	
S dam			

dam, even if we know neither the absolute values of the height, velocity and other constants of that dam or anything about the ground on which it stands, the earthquake motions at the foundation of the dam will be ascertained easily by utilizing the earthquake records obtained at the top of it.

The way of estimating the value of $2H/V$ is from the equation $T_s=4H/V$, in which T_s is the predominant period of the earthquake motions observed at the top of a dam.

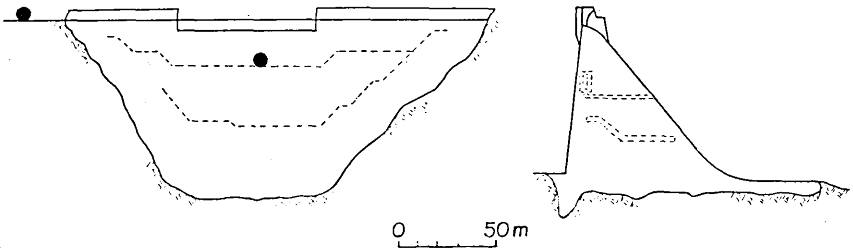

Fig. 2. Sketch of the T dam. Black circles represent the seismographs.

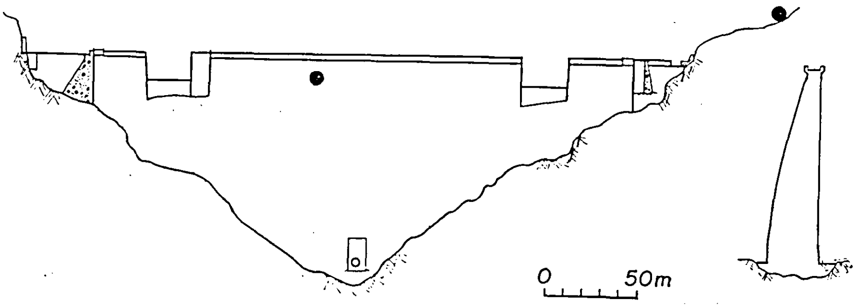

Fig. 3. Sketch of the K dam. Black circles represent the seismographs.

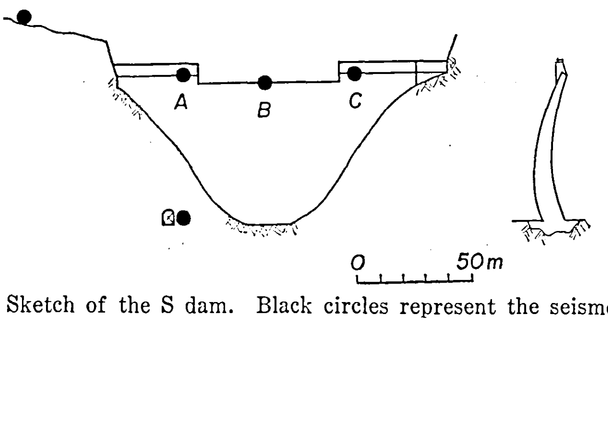

Fig. 4. Sketch of the S dam. Black circles represent the seismographs.

Now, in order to get the values of T_s of the dams, period distribution curves are obtained from the seismograms recorded at the upper part of the dams as shown in Figs. 5–7. The values of T_s adopted in the theoretical study are shown as vertical strips in Figs. 5–7.

The final results of the theoretical study by means of equation (1) are illustrated in Figs. 8–10. In each figure, the uppermost curve, (a), represents the actual record of earthquake motions obtained at the upper part of each dam and the middle (b) or (b′), and the lowest, (c), curves, respectively are the actual record at the bottom of or the ground close by the dam and the theoretical result obtained by using equation (1).

As will be seen from Figs. 8–10, the agreement of the observational result, (b), (b′), and the theoretical one (c), in each dam is well beyond expectation.

It seems somewhat strange that the agreement of the record at the

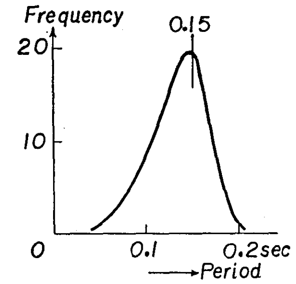

Fig. 5. Period distribution curve of the earthquake motion obtained at the upper part of the T dam.

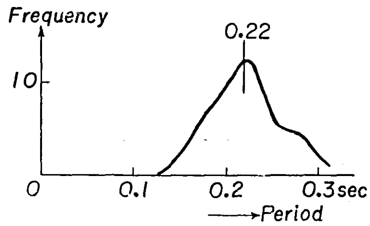

Fig. 6. Period distribution curve of the earthquake motion obtained at the upper part of the K dam.

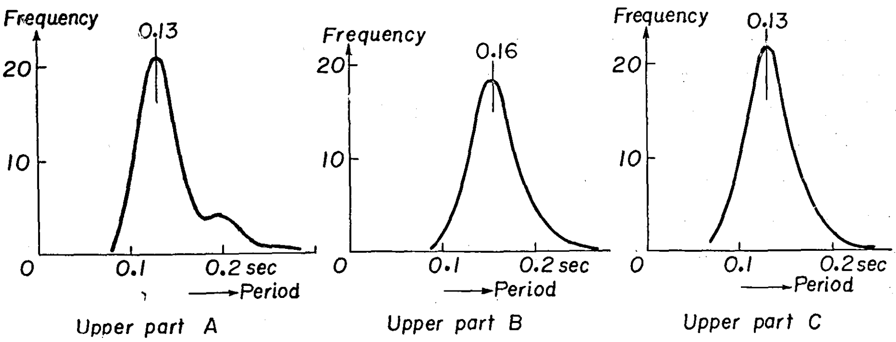

Fig. 7. Period distribution curves of the earthquake motions obtained at the upper parts of the S dam.

bottom of a dam and the one at the ground surface close by it is considerably good as shown in Fig. 10. This however is merely the result of the fact that the wave length of the main parts of the incident seismic waves is satisfactorily large compared with the height of the dams.

The difference of the predominant periods of the earthquake records obtained at the upper parts A or C and B of the S dam as shown in Fig. 7 correspond approximately to that of the heights. It is natural to state, with the following considerations in mind, that the kind of waves transmitted in the dams are distortional waves. This is because the calculated value of the apparent transmission velocity of waves in the dams, V, using the relation $4H/T_s$ becomes about 2 km/sec and the velocity of distortional waves in the dams estimated by the velocity of dilatational waves of 3.5–4.0 km/sec and the Poisson's ratio of 1/6 is 2.0–2.5 km/sec.

From the results of the present investigation, we know that the vibration of a dam due to earthquake motions should be treated as the multiple reflection phenomena of waves.

In general, the amplitudes of vibration at the top of the actual dams become relatively large at such periods as are synchronous with the apparent natural periods of them and take naturally a decaying type. It is natural for it to be considered that the fact mentioned above is due to the energy dissipated outwards through the neighbouring medium, the problem, being now of wave propagation and not of pure stationary vibration with energy condensed in a conservative system.

3. Conclusion

From the results of the present as well as the previous investigations, we knew that the vibration of an actual structure due to earthquake motions should be treated as the multiple reflection phenomena of waves.

It should be borne in mind that the usual way of assuming all the sources of damping to be included in such terms in differential equations of motion that specify the damping forces, namely, viscous fluid damping, solid friction damping, etc., is not correct, at any rate in the present or similar problem.

In conclusion, we wish to express our sincere thanks to Dr. Tadashi Takahashi of the Central Research Institute of Electric Power Industry for cooperation, especially, in making the seismograph records available

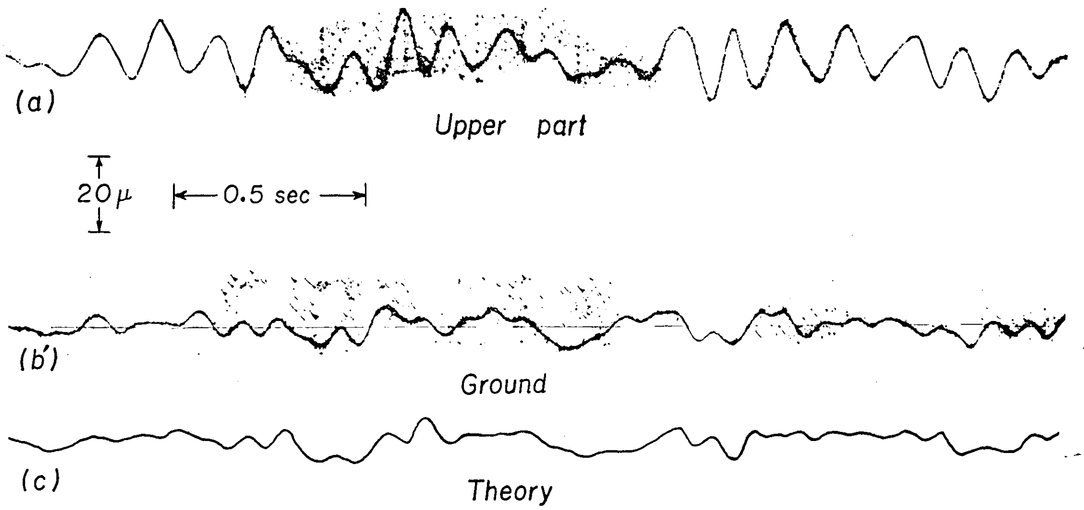

Fig. 8. T dam. Original×1/2.

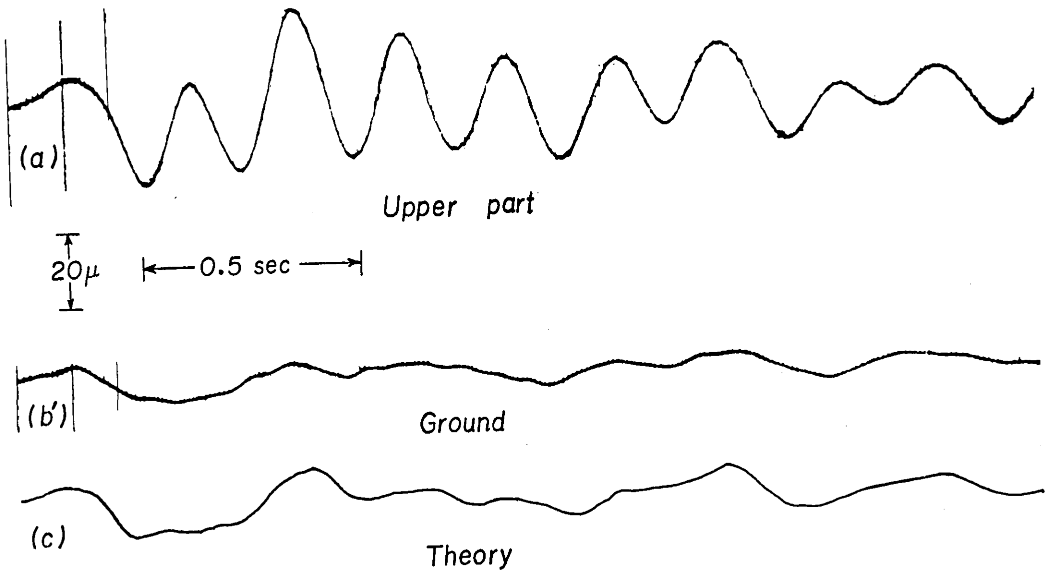

Fig. 9. K dam. Original×1/2.

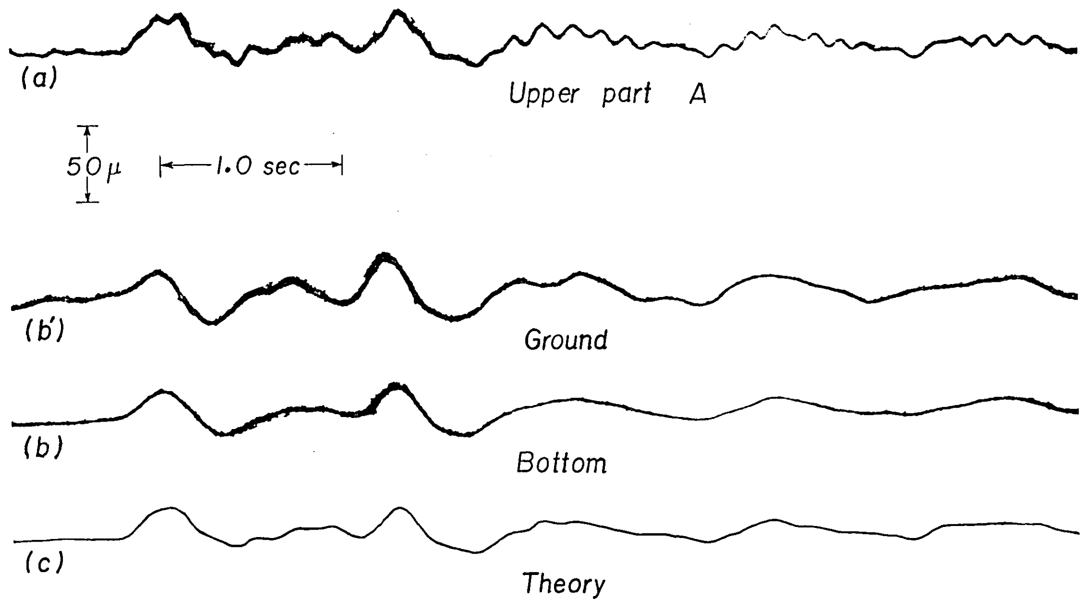

Fig. 10a. S dam: upper part A. Original×1/2.

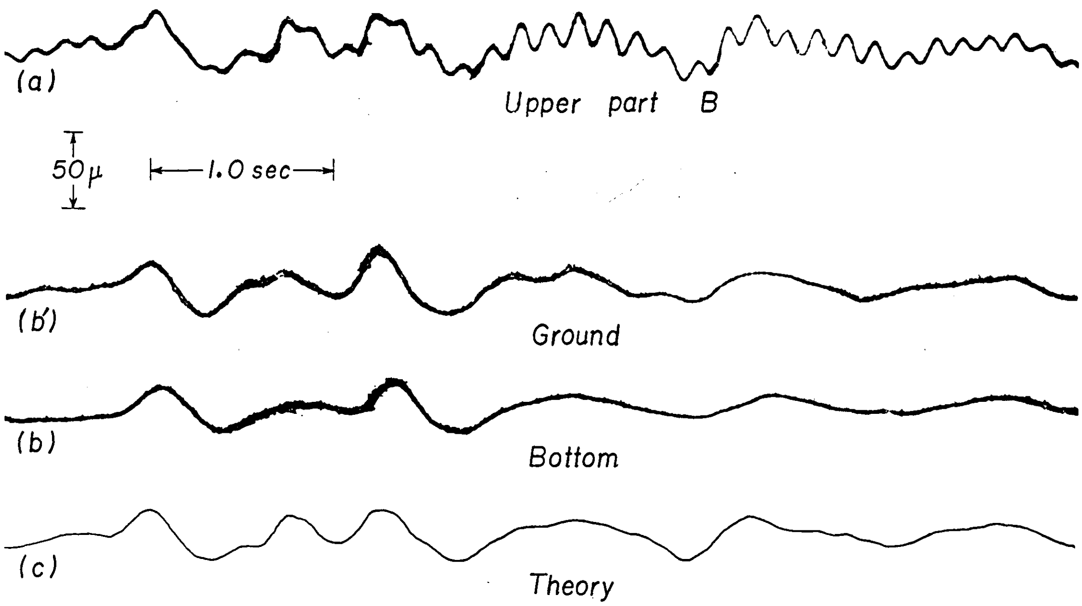

Fig. 10b. S dam: upper part B. Original×1/2.

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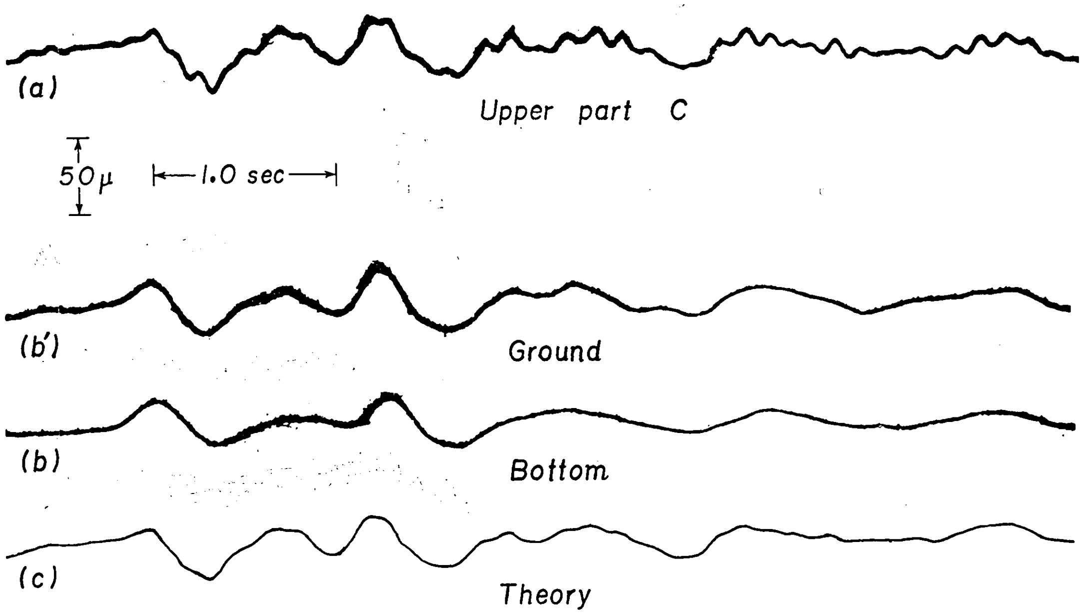

Fig. 10c. S dam: upper part C. Original×1/2.

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to us, without which successful results could not have been obtained.

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12. 地震動による構造物振動の新しい問題　第2報 (ダムの場合)

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吉沢静代

前回の研究結果では，地震動による建物振動は，地震波の重複反射の現象にほかならないことと，建物の振動減衰は，その内部では無視できるぐらい小さくて，ほとんどが，基礎と地盤との境界面で起こることが，よくわかつた．

本研究では，前回と同様に，弾性体内での地震波の重複反射の理論解を，3つの実在コンクリートダム（塚原ダム，上椎葉ダム，佐々並川ダム）で観測された，それぞれ1つの地震に応用してみた．

その結果，コンクリートダムの場合にも，前述した，建物の場合に得られた結論と同じことが言えることがわかつた．

なお，地震動でコンクリートダムの振動を誘起する地震波は，コンクリート内を伝わる振り波の性質をもつていることもわかつた．
