BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 40 (1962), pp. 67-70

2. *Oscillations of Water in a Reservoir, Observed in the case of the Kita Mino Earthquake on Aug. 19, 1961.*

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(Read Dec. 19, 1961.—Received Dec. 28, 1961.)

A strong earthquake occurred in the central part of the Japan Main Land and was reported in the previous issue of this journal[1]. Just at the time of the earthquake, Mr. Kihei Noda, the mayor of Shiratori Town happened to be standing on the Miboro Dam with a few men and saw the surface of the water in the reservoir became wavy soon after the earthquake was felt. The waves seemed progressive from west to east. On the other side, a watermark in the reservoir was found to be wet after the earthquake 40 cm above water level.

Oscillations of water in shallow vessels and water pools have been observed at the time of strong earthquakes, and this phenomenon is taken into consideration in classifying the intensity of earthquakes. In the case of the great Lisbon earthquake of 1755 unusual disturbances of water were observed. Seiches in rivers, lakes and pools in England and Scotland, at distances of up to 2000 km from the epicentre, were reported and studied by scientists in Europe[2]. Takeo Suzuki[3] investigated seiches in Tokyo Bay on the occasion of the great earthquake of Sept. 1, 1923. He considered that the seiches were caused by the tilting of Tokyo Bay which was manifested by precise geodetic surveys. Further A. Imamura and T. Kodaira[4] reported that a tide gauge in Lake Ashi, Hakone, recorded seiches of the lake water in the case of the Idu earthquakes of 1930. T. Suzuki's theory is ingeneous, but it cannot explain the other cases. Difficulties in the explanation may be met especially on the amplitude relation between the motions of the ground and of the water. Civil engineers have studied dynamic water pressure on dams due to earthquake motions. They did not arrive at

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1) *Bull. Earthq. Res. Inst.*, **39** (1961), 857-868.

2) Ch. DAVISON, *A History of British Earthquakes*, Cambridge, 1924.

3) Takeo SUZUKI, "Seiche in Tokyo Bay caused by Land Upheaval on the occasion of the great earthquake of September 1, 1923," *Bull. Earthq. Res. Inst.*, **13** (1935), 266-289.

4) Akitune IMAMURA and Takao KODAIRA, *Zisin* (*Earthqnake*), **4** (1932), 57-70.

definite results, and no records of pressure were obtained, Here the writer has studied the oscillations of water, connected with the nature of the motions of strong earthquakes.

The water waves seen by the mayor would be different from seiches. In an effort to gain detailed data on the waves, the writer asked an operative of the Miboro electric power station who saw the waves from the intake tower of the reservoir. He said that at the time of the earthquake the weather was calm and there were no waves on the water surface before the earthquake. When the earthquake occurred waves in the dam were propagated from upstream. The wave-length seemed to be 2 m.–1.5 m. The velocity of the propagation was faster than that of capillary waves created by winds, and slower than motor boats in speed. The Miboro Dam is situated in Shirakawa-mura, Ōno-gun, Gifu Prefecture, and at present the highest rockfill dam in Japan. The height of the dam is 131 m, length 405 m, the depth at the intake 91 m, the surface area of the reservoir 8.8 km^2 and the volume of water in the reservoir about 3×10^8 m^3. And the dam was near the epicentre, about 30 km east.

The wave-length of the waves were so small compared with the depth of the reservoir that the waves were regarded as surface waves. In theory, the relation between velocity and wave-length is given by the formula

$$c^2=\frac{g\lambda}{2\pi}$$

where c denotes the velocity of propagation and λ the wave-length. Assuming the wave-length 2 m, or 1.5 m as reported above, the velocity c and the period of the waves T were calculated:

$$c=1.8\,\text{m/s and } T=1.1\,\text{s}, \quad \text{for } \lambda=2\,\text{m}\,,$$
$$c=1.6\,\text{m/s and } T=1.1\,\text{s}, \quad \text{for } \lambda=1.5\,\text{m}\,.$$

These values may be consistent for the water waves seen by the naked eye as previously outlined.

There was a discrepancy in the reports as to the direction of the waves given by the two observers, the mayor from west to east and the operative from upstream to the dam. The contradiction may be solved on considering the condition of the water surface. Near the dam, floats were moored in a straight chain to protect the intake from driftwood. And the line of floats was obliquely projected in the reservoir. When the waves came from upstream, the mayor on the dam might have observed the movement of the floats shifting from west to east as waves. The waves were seen passing away and no standing waves were observed because the sides of the rock-fill dam are rough and at a gentle slope, moreover the bottom of the reservoir is covered with withered trees subsided. Thus the water waves caused by the earthquake might soon die away.

The amplitude of the waves as evidenced from the watermark, 40 cm, might be the sum of the amplitudes of the waves and that of seiches activated similarly by the earthquake as the examples abovementioned. But after due consideration of the seiches of the Idu earthquake, in the present case the amplitudes of the seiche, would be 10 cm in round numbers. On the other hand, the amplitude of the earthquake motion would not be as large as the water waves. Theoretically an elastic wave train cannot be transformed into larger waves in water by refraction[5] than that originated in solid. At Miboro, earthquake sounds like firing were heard. In general near the epicentral region, earthquake motions will be impulsive and have quick vibrations, which are felt for rather long periods as written in the previous paper[6]. Now a hypothesis was ventured that the water waves were generated by impulsive motions of the ground at intervals of about one second, which is equal to that of the water waves. Such a series of impulses might be recorded on seismograms as one second period vibrations of the ground. Actually, vibrations of one second period were recorded in seismograms of the earthquake obtained at Kanazawa and Wazima.

Another posibility is that rockfalls in the reservoir might have caused the waves. But there were no rockfalls near the dam sufficiently violent to generate the waves discussed in this paper.

The above may be a deduction of the nature of strong earthquake motions in the epecentral region from a phenomenon accompanying the earthquake.

At the end of this study, the writer expresses his thanks to members of the Dengen-kaihatsu Kabushiki-kaisha (the Electric Power Development Co. Ltd. Japan) who gave him the data on the waves.

5) See for example, C. G. Knott, The physics of earthquake phenomena, Oxford, 1908, 175-177, or W. M. Ewing, W. S. Jardetzky and F. Press: Elastic waves in layered media, New York, 1957, 79-83.

6) F. KISHINOUYE and I. ONDA, *Bull. Earthq. Res. Inst.*, 39 (1961), 857-868.

2. 1961 年北美濃地震の時に見られた貯水池の波について

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北美濃地震の時に御母衣ダムの貯水池の表面に波が見られ，その波長は約 2m と目測された．この波長は水深と比べて短いので水の表面波と考え，理論式から求めると速度は約 2m/s，周期約 1 秒となつて，この程度ならば観察されたものと考えられる．この波が地震動によつて起されたとすると，振幅の点が説明し難い．そこで衝撃性の地動が水の波を起したという仮説をたてた．衝撃性の地動が時間をおいて起れば，地震記象上に表われた地震動の周期性のものと見做されるであろう．

以上は震央附近の大地震の性質を調べる方法として，地震に伴つて起つた現象を利用したものである．