12. *A Torsional Pendulum Low-pass Filter Applied to the Study of the Earthquake Waves.* (*Part 2*)

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§ 4. On some results obtained from the use of the filter to the seismograms of an earthquake :—

After confirming that our apparatus works as a satisfactorily quantitative low-pass filter by the preliminary tests reported in the previous paper, the writer applied the filter for investigating actual seismograms of the earthquake of May 23th, 1938, which took place at the offing of Sioya.

($\lambda=114.45°E$, $\varphi=36.70°N$, Shallow)

The epicenter and the observational positions of the seismograms are shown in Fig. 6. Fig. 7 shows some examples of the original seismograms, and the filtered curves. In this figure, the numbers 1, 2, 3, etc.

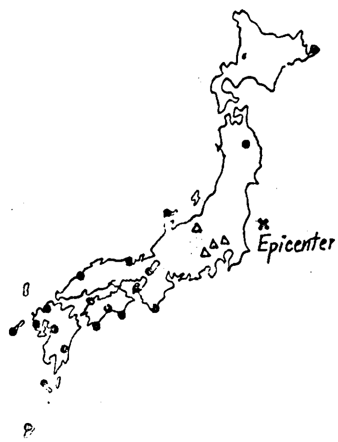


Fig. 6. The epicenter × and the observational positions (● and △).

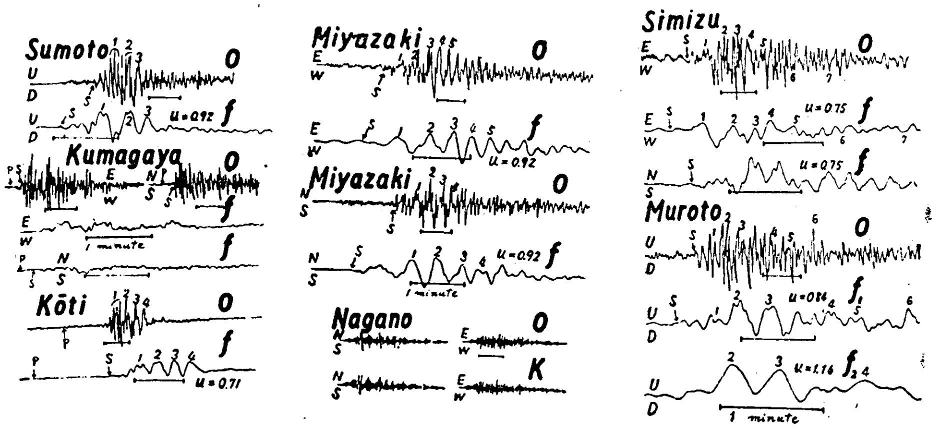


Fig. 7. Some examples of the original seismograms (O) and the filtered long curves (f_1, f_2).

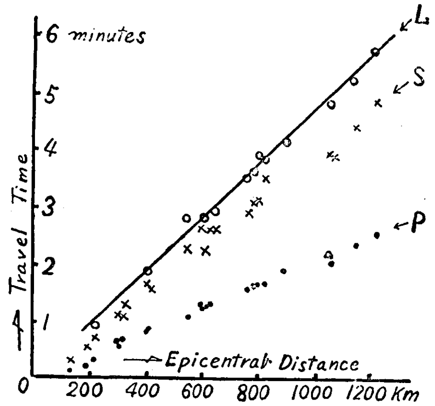
indicate the corresponding waves on the seismograms and on the filtered curves. O's are the seismograms and f_1, f_2 are the curves filtered once and twice respectively. T_0 is the working period of the filter pendulum and u's are the ratio T_0/T, where T's are the periods of the filtered long waves. The last curve in this figure concerning Nagano is not the filtered curves but is the wave forms described by the pen K which is attached to the arm B as was shown in Fig. 2 in the pervious paper. This curve shows how accurately we can follow the seismograms by the hand method reported before.

Table I.

		△ in degrees	p-s	P-L			T			
				E-W	N-S	U-D	E-W	N-S	U-D	
1	Tukubayama	0°18′	0ᵐ 12.3ˢ							
2	Kumagaya	1 50	21.7							
3	Yokohama	2 03	24.5		38.5ˢ			31ˢ		○
4	Nagano	2 36	31.2							
5	Kōhu	2 41	33.7							
6	Wazima	3 40	53.2	1ᵐ 26.5ˢ	1ᵐ 26.5ˢ		14.0ˢ	14.0		○
7	Toyooka	5 30	1 02.2	1 16.5		1ᵐ 32.0ˢ	27.0		27.5ˢ	◎
8	Kyōto	5 02	1 13.0	1 40.0			19.0			◎
9	Sumoto	5 55	1 14.5			1 30.0			27.5	◎
10	Sionomisaki	5 47	1 16.0		1 24.0			22		◎
11	Muroto	6 58	1 18.0			1 52.2			25	◎
12	Nemuro	7 10	1 25.9	1 35.0			30			◎
13	Kōti	7 16	1 30.0	2 13.6			23		25	◎
14	Matuyama	7 44	1 49.2	2 10.0	2 10.0		20	25		○
15	Hamada	7 51				2 32.0			26	◎
16	Simizu	8 07		2 04.0	2 07.0		28	22.6		◎
17	Hukuoka	9 35		3 08.0		3 08.0	20		22.0	◎
18	Kumamoto	9 42	1 45.6	2 17.0	2 17.0		56.5	23.4		○
19	Titizima	9 47	1 49.3		2 19.3		32	30	30	◎
20	Miyazaki	9 37	1 59.3	2 34.0	2 44.0	2 39.0	32	30	29	◎
21	Nagasaki	10 22	2 00.9	2 52.0	2 32.9		23.5	22		◎
22	Okusima	11 08	2 08.0	3 08.0			28			◎
23	Tomie	11 26	2 44.8	3 10.0			20			◎

First we can notice from these curves that there exist certainly some propagational waves having long periods. The data concerning these long waves (L) are given in Table 1. Fig. 8 is a travel-time curve tor these long waves together with that of the P and S waves. Calculating the velocity of these waves from this curve, it was found to be approximately 3.8 km/sec.

Besides the dispersion phenomena, many seismologists have observed that the velocities of surface waves are different according to their paths of propagation[7)-12)]. The velocity we have obtained agrees well with that given by *B.* Gutenberg and by C. F. Richter for the Love waves which are propagated under the North American continent (taking the period at 30 sec.). The marks ◎ and ○ in the last column of Table 1 indicate the well-recognizable appearance of the long waves.



Eig. 8. The travel-time curve of the filtered long waves (L).

There are some seismograms from which the long waves could not be filtered out clearly. Especially on the filtered records for seismograms obtained at Tukubayama, Kumagaya, Nagano and Kōhu, the long waves are not filtered out.

The Kumagaya's is shown in Fig. 7. The positions of these stations are shown in Fig. 6 by △. Concerning the generation of surface waves, this fact is an interesting one and deserves to be studied in future.

There is a point to be considered about the accuracy of the onset of these recorded long waves, that is, about the time lag of the motion of the filter pendulum against the incident torsional vibrations applied to the pendulum.

On our filtered records, the periods of the long waves are remarkably large compared with those of the *P* and *S* waves, so we may solve the problem simply by studying how the torsion pendulum moves if a sinsoidal torsional vibration is suddenly applied to its head. This problem is reduced to solve the equation of the torsion pendulum's motion,

$$\ddot{\beta}+2\varepsilon\dot{\beta}+n^2\beta=an^2\sin pt$$

on the initial conditions, when $t=0$; $\dot{\beta}=0$, $\beta=0$. (3)

7) G. Angenheister, *New Zealand Jornal of Science and Technologie*, **6**, **214** (1921).
8) P. Byerly, *Gerl. Beitr. zur Geophy.* **26** (1930).
9) W. Rohrbach, *Zeit. für Geophys.* **8**. 113 (1932).
10) W. Mühlen, *Zeit. für Geophys.* 8 (1932).
11) D. S. Cardar, *Bull. Seis. Soc. Amer.* **24** (1934).
12) B. Gutenberg, C. F. Richter, *Gerl. Beitr.* **47,92** (1936) etc.

The general solution of this equation is

$$\beta=e^{-\varepsilon t}(A\sin n\sqrt{1-h^2}t+B\cos n\sqrt{1-h^2}t)+\frac{u^2}{\sqrt{(1-u^2)^2+4h^2u^2}}a\sin(pt-\delta), \quad (4)$$

$$\tan\delta=\frac{2hu}{1-u^2},$$

where A, B are constants to be determined by the initial conditions (3), and ε, h, u, are the same quantities as expressed in the previous paper, that is $\varepsilon=R/I,\quad h=\varepsilon/n,\quad u=n/p.$

From (3) and (4), A and B are determined as follows.

$$A=\frac{au\{(1-u^2)+2h^2u^2\}}{\sqrt{1-h^2}\{(1-u^2)+2h^2u^2\}},\quad B=\frac{2hu^3a}{(1-u^2)^2+4h^2u^2},$$

so, (4) becomes

$$\beta=\frac{u}{\sqrt{1-h^2}\sqrt{(1-u^2)^2+4h^2u^2}}e^{-\varepsilon t}a\sin(n\sqrt{1-h^2}t-\Delta)$$

$$+\frac{u^2}{\sqrt{(1-u^2)^2+4h^2u^2}}a\sin(pt-\delta), \quad (5)$$

where $\tan\Delta=-\frac{2hu^2\sqrt{1-h^2}}{(1-u^2)+2h^2u^2},\quad \tan\delta=2hu/(u^2-1).$

In our case, the value of h is 0.64 ($\because\ h^2=0.4$).

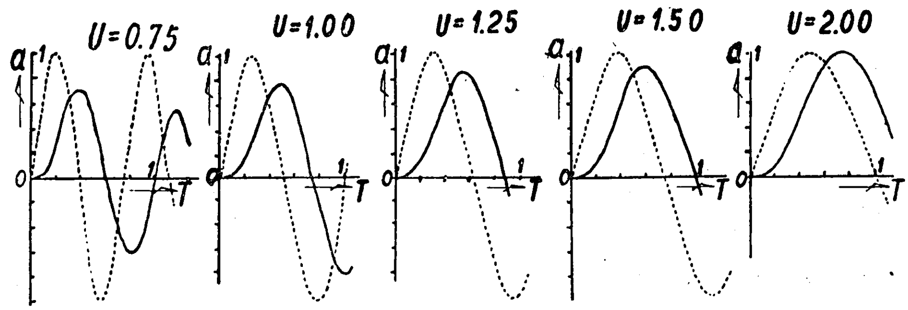


Fig. 9. The initial motion of the pendulum (solid line) caused by a sinsoidal torsional vibration (dotted line) suddenly applied to its head.

Fig. 9 shows the initial motion of the pendulum (solid line) caused by a sinsoidal torsional vibration suddenly applied to its head (dotted line), being calculated from the solution (5) taking $h=0.64$ and $u=0.75$, 1.00, 1.25, 1.50 and 2.00.

In this figure, T, the proper period of the pendulum, and a, the amplitude of the incident waves, are taken respectively as the units of abscissa and ordinate.

Seeing these results, we know that the determination of the onset time of these long waves may have the time error of approximately 5% (when approx. $u<1.50$) and 10% (when approx. $u>1.50$) of T.

In our case, the pendulum was used at the proper period of 20~30 sec, and u was 0.75~1.3, so that the time lags are approximately 1~3 sec. Every point in the travel-time curve of the long waves was taken after these corrections were made.

Judging from the fact that the filtered long waves have all remarkable vertical components, they seem to be of the Rayleigh-type.

In order to examine this point, the writer investigated the vertical ground motion which is parallel to the direction of the wave propagation using the filtered long waves at Miyazaki. (It is regretable that this was the only position at which 3 component seismograms were obtained which were necessary for this purpose.) The result which is shown in Fig. 10 shows a theoretically requested retrograd fashion of the motion of a particle at approximately 50 seconds later from the beginning of the long waves. (The numbers 20~70 on this figure mean the times reckoned from the beginning of the long waves.)

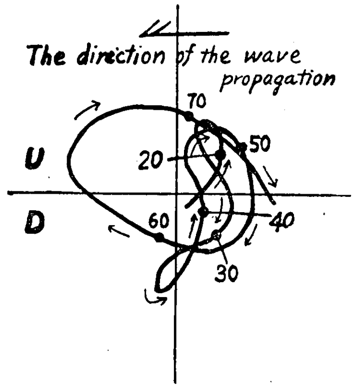


Fig. 10. The vertical ground motion at Miyazaki due to the filtered long waves.

Fig. 11 gives some exmaples of horizontal ground motions concerning the long waves in two directions, (a) parallel and (b) perpendicular to the direction of the wave propagation at Miyazaki, Simizu and Matuyama. In drawing these figures, the writer took the propagational direction to be a straight line drawn from the epicenter to these observational positions, but actually, there may be some deviations. These problems must be studied with much more data in future.

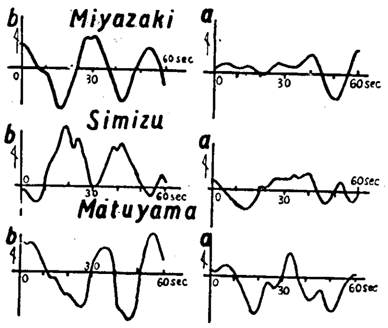


Fig. 11. Some examples of the ground motions in two directions concerning the filtered long waves.

Besides, since all these filtered waves have components perpendicular to the direction of the wave propagation, they seem to be Love waves.

After all, the actual orbit of the ground motion due to the filtered long waves is some complex one, which may be due to the fact that Rayleigh and Love waves are not well separated in these near earthquakes.

§ 5. Conclusion: Though our present study, the filtering of long waves from near earthquakes, is only at first stage, it leaves us many problems to be studied on surface waves in near earthquakes. Although our apparatus, in its present form, has proved to work satisfactorily for studying the problems of surface waves in near earthquakes experimentally, it has still some inconvenient point. Especially, the fact that the oil is used as a damping medium makes this apparatus as an inconvenient one. For, we must use a thermostat to keep the temperature of this oil constant. The writer is now constructing a much more convenient one with magnetic damper with which experiments can be made in lighted room, but not in a dark room.

In conclusion, the writer wishes to express his hearty thanks to Prof. C. Tsuboi and Mr. S. Miyamura who gave the writer many remarks in the course of his experiments, and to Mr. S. Honma, a member of The Central Meterological Observatory, who was kind enough to lend me the seismograms studied.

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12. 捩り振子を應用した低域濾波器による地震波の研究

地震研究所　秋 間 哲 夫

近地地震の記象から表面波をとり出す目的で，捩り振子を應用した低域濾波器を作製し，種々の予備實驗を經た後で，實際にある一つの地震についての各地の記象をこの濾波器にかけて見たところ，表面波とおぼしき 30 秒前後の周期をもつた傳播性の波が，S 波の後に存在することが分つた．走時曲線をつくつて見ると，その速度は約 3.8 km/sec である．三成分そろつた記象がごく僅かだつたので，この波の性格ははつきりきめられないが，ラヴ波的な面も，レーリー波的な面も見られる．又震央距離が約 2° 30′ 以内の地點の記象からは，之等の長周期の波が濾波しえなかつたことも注意されよう．之等の點に關して今後いろいろの地震について調べてゆきたいと思つている．