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On the Observations of the Long Period's Oscillations of the Earth by Means of the Extensometers and the Water-tube Tiltmeter

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Abstract

In this paper, the long periods' oscillations of the earth's strains have been observed with highly sensitive extensometers at Osakayama Observatory, Kishu Mine and Suhara Observatory in the Chilean Earthquake, the Alaskan Earthquake and the Aleutian Earthquake. The tilt-oscillation also has been observed with water-tube tiltmeter at Osakayama Observatory in the Aleutian Earthquake.

The observed records of these oscillations have been analyzed by means of auto-corre lation. According to these observations, the extensional oscillation of the earth-crust consists of about ten or shorter a little minutes' periods in addition to the ones longer than ten minutes and tilt-oscillation is dominant in about six minutes' periods. Moreover, some power spectra have been calculated by means of the Fourier analyses from these auto-correlation functions.

1. Introductions.

In the great earthquakes, we have sometimes observed the long period's oscillating strains at more than several minutes, which are thought to be the earth's free oscillations. Now, we need not describe about the general studies of the earth's free oscillation, because many introductions[1][2][3] related to their studies have been published. However, it is not easy to distinguish the long period oscillations covered with the dominant short periods' ones. There are, still more, many open to discussion in the connection to their magnitude and their truth or falsehood of the observed changes. In this paper, the long period oscillations are observed with highly sensitive extensometers at Osakayama Observatory, Kishu Mine and Suhara Observatory in the Chilean Earthquake (1960), the Alaskan Earthquake (1964) and the Aleutian Earthquake (1965). The records of these observations contain dominant oscillations whose apparent period is about ten minutes beside about thirty and sixty minutes on the extensometers, and is about six minutes on the water-tube tiltmeter. From these records, their auto-correlation functions and then some power spectra are calculated by means of the Fourier analyses from their auto-correlation functions.

Some researchers[4] assumed that the shorter period's oscillations could not be dominate, because of the horizontal inhomogeneties of the earth crust and of the duaration time of the earthquake. But the shorter period's oscillations are considerably dominant in our observations. So it is necessary to think of something to relate both results.

2. Observatory and instrutment.

These observations were made at chiefly Osakayama Observatory, and have been done partially at Kishu Mine and the Suhara Observatory. The Osakayama Observatory is situated at 135° 59.6′ east latitude and 34° 54.5′ north longitude. The Kishu Mine is situated at 135° 53.4′ east latitude and 33° 51.7′ north longitude, and the Suhara Observatory at 135° 11.7′ east latitude and 34° 02.6′ north longitude. The mean distances from the ocean to these observatories are 65 km at Osakayama, 15 km at Kishu and 50 m at Suhara.

The standards and abilities of the instruments related to these observations are shown in Table 1.

TABLE 1.

Instrument	Type	Direction of Observation	Station	Length of Base.	Sensitivity		
					in Chilean	in Alaskan	in Aleutian
Extensometer	H-59-B	N-S (N_1)	Osakayama	6.6m.	1.11×10^{-8}		
〃	〃	E-W (E_1)	〃	5.3 〃	1.01×10^{-8}		
〃	〃	S38°W-N38°E (L_3)	〃	24.0 〃		0.086×10^{-8}	0.017×10^{-8}
〃	H-59-D	S38°W-N38°E (L_4)	〃	34.0 〃			0.0079×10^{-8}
〃	H-59-B	S52°E-N52°W (C_1)	〃	10.0 〃		0.043×10^{-8}	0.033×10^{-8}
〃	H-59-C	N-S	Suhara	8.0 〃		0.183×10^{-8}	0.273×10^{-8}
〃	Wire & Spring	N30°W-S30°E	Kishu	4.4 〃		1.22×10^{-8}	
Water-tube Tiltmeter	Eto	N38°E	Osakayama	60.0 〃			0.0173″

The H-59-type[5] extensometer consists of a standard scale made from super-invar rods or pipes (10 or 30 millimeters in diameter) and magnifier which consists of a system which transform the earth's strain into the inclination of the axis of the horizontal pendulum, and the horizontal pendulum for the amplification of the transformed inclination. Its sensitivity is able to be adjusted in the range between 10^{-8} and 10^{-10} per one millimeter on the record at any time. The wire-and-spring type[6] extensometer consists of the super-invar wire (1.6 millimeter in diameter) which is slackened with a spring on its center. Its maximum sensitivity is about 10^{-8} per one millimeter and is not variable. Both types extensometers have been devised by I. Ozawa. The water-tube tiltmeter[7] consists of two tubs which are connected with the tube (38 millimeter in diameter) of hard vinyl-chloride, and are filled with water. One of the tubs is about 70 centimeters in its inner diameter and the other is about 10 centimeters. There is a floter in the smaller tub in order to indicate any change between both distances from their water-level to the fixed points on the ground close to both these tubs. This instrument has attempted to be set experimentally by T. Eto. Its sensitivities are 0.017" and 0.047" per one millimeter on the record. The observations with these instruments have been made by I. Ozawa and his engineers at Osakamaya, Kishu and Suhara. The speeds of their continuous records of the observations are 40 (E_1 and N_1 at Osakayama, N 30° E at Kishu, and N at Suhara), 63 (L_3 and L_4 at Osakayama), 105 (C_1 at Osakayama), 263 (L_3 and Water-tube at Osakayama) and 400 millimeters (L_4 at Osakayama) per day.

3. The observed earthquakes.

Recently, we have observed three great earthquakes as in the following Table 2.

TABLE 2.

Name of Earthquake	Date	Epicenter	Magnitude
Chilean Earthquake	May 23, 1960	41.0° S., 73.5°W.	8.25—8.75
Alaskan Earthquake	Mar. 28, 1964	61.1°N., 147.6°W.	8.0—8.5
Aleutian Earthquake	Feb. 4, 1965	52.0°N., 178.0°E	8.0

The epicentral distances and the azimuths of the seismic paths of these earthquakes at Osakayama are calculated as following Table 3.

TABLE 3.

Earthquake	Epicentral Distance	Azimuth
Chilean Earthquake	147.3°	113.6°
Alaskan Earthquake	52.0°	35.1°
Aleutian Earthquake	32.7°	63.6°

Fortunately, the azimuth of the seismic path is nearly parallel and perpendicular to the observing directions of the extensometer L_3 (S 38° W) and C_1 (S 52° E), respectively, in the Alaskan Earthquake.

4. Observations of the earth's free oscillations.

Our extensometers and water-tube tiltmeter have the sufficient abilities to record the earth's free oscillations, if their amplitudes are bigger than or as large as 10^{-9} or 0.01", respectively. But all these instruments have not always been put under the full sensitive conditions to record these phenomena because of the following reasons.

(1) the ground around the observatories will be deformed anomalously by unexpectable causes,

(2) the object of these observations are not only for the earth's free oscillation.

Photo. 1 (a), (b), and (c) show the extensional records observed with the extensometers on the N-S (N_1) and E-W (E_1) components at Osakayama, and on N 30°W-S 30°E component at Kishu, respectively, in the Chilean Earthquake. Photo. 2 (a) and (b) show the extensional records of N 38°E-S 38°W

(L_3) and S 52°E-N 52°W (C_1) components at Osakayama in the Alaskan Earthquake. Photo. 3 (a), (b) and (c) show the extensional records of N 38°E-S 38°W (L_4) and N 52° W-S 52°E (C_1) observed with the extensometers, and tilting record of N 38°E direction-component observed with water-tube tiltmeter, respectively, at Osakayama in the Aleutian Earthquake. Photo. 4 shows the extensional records of N-S component at Suhara in the Alaskan and Aleutian Earthquakes.

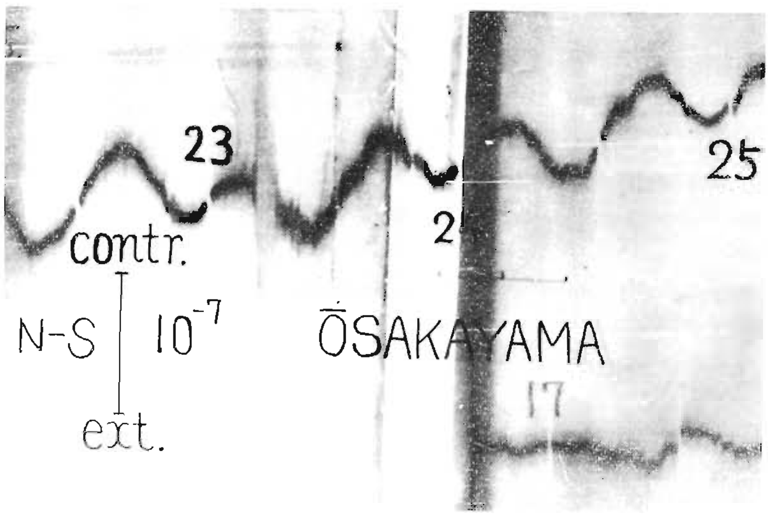

Photo. 1. (a)

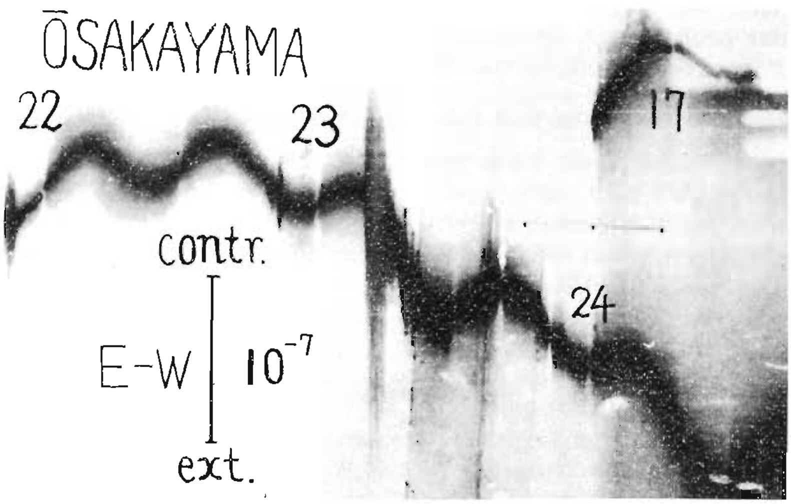

Photo. 1. (b)

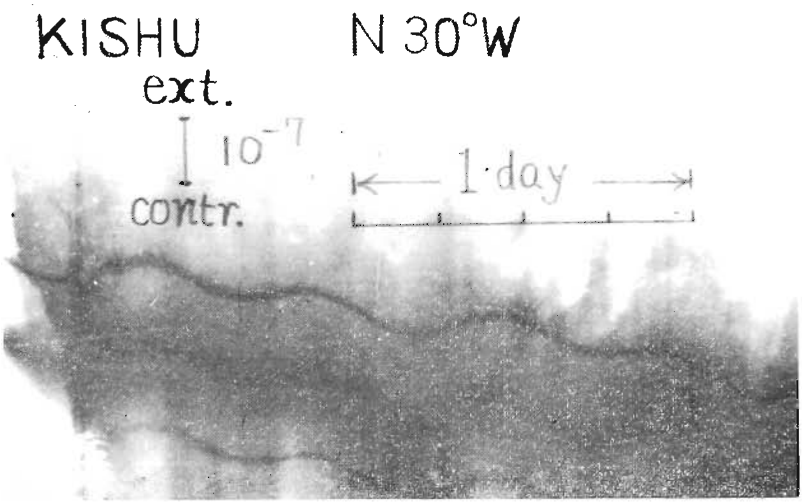

Photo. 1. (c)

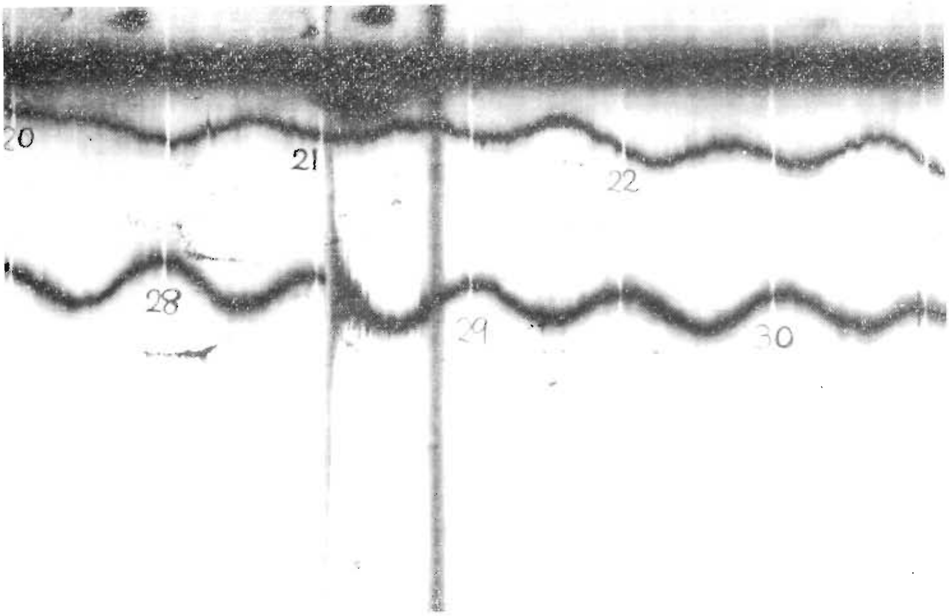

Photo. 2. (a)

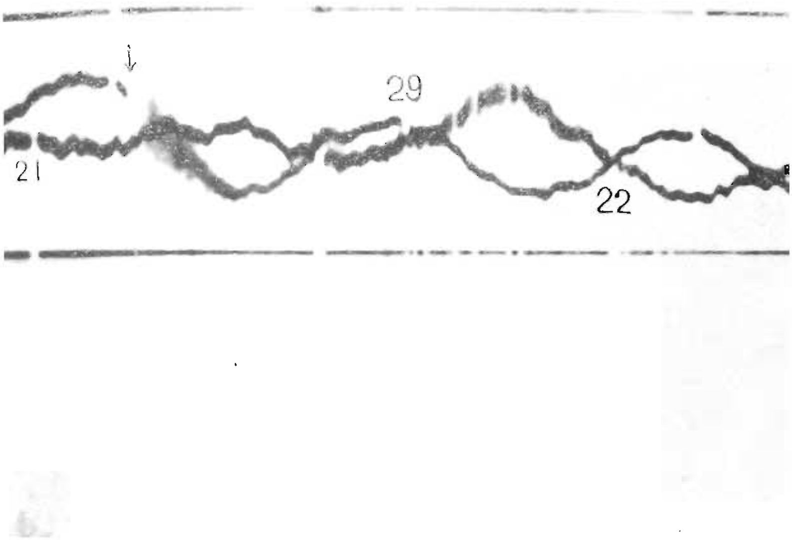

Photo. 2. (b)

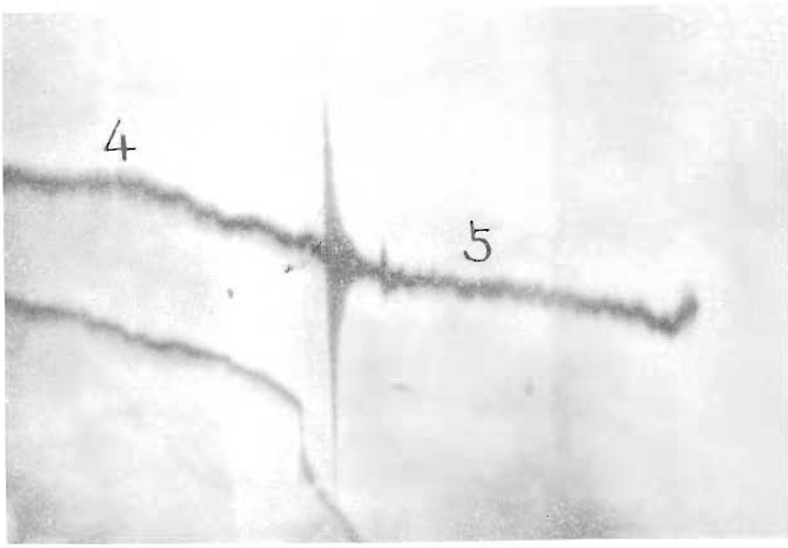

Photo. 3. (a)

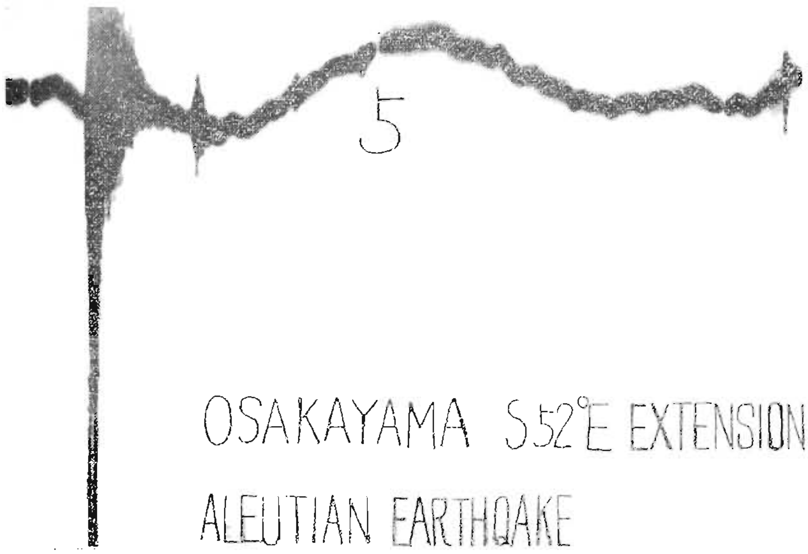

Photo. 3. (b)

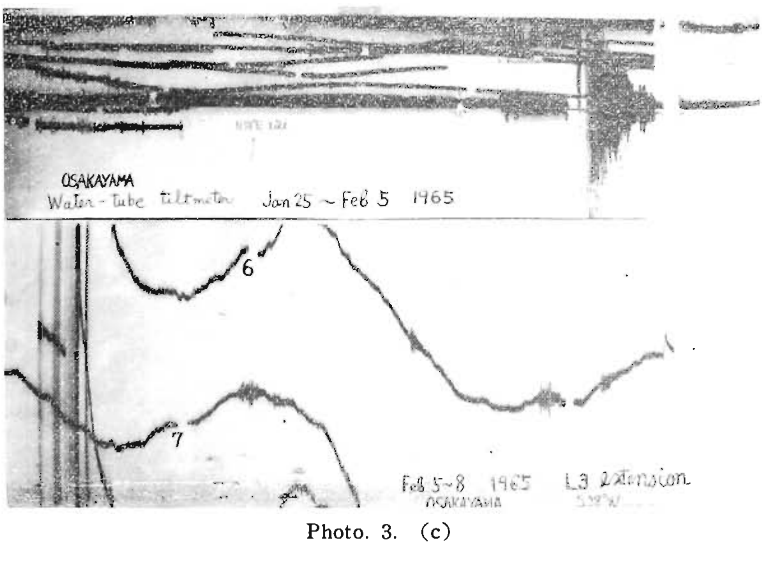

Photo. 3. (c)

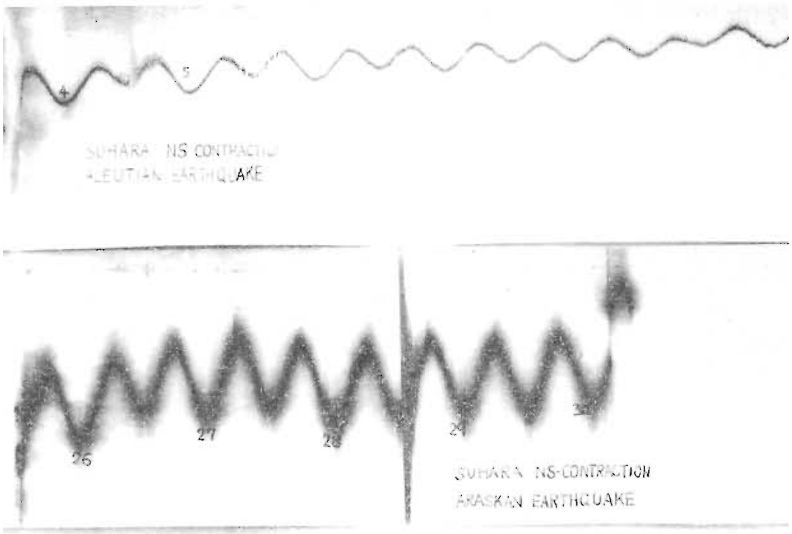

Photo. 4.

5. Analyses and discussions.

We have calculated the auto-correlation curves of these observing curves. In order to simplify these calculations, we have calculated that of the series of time derivatives of the observing curves and also have used the simple (sign) auto-correlation methods[8]. Thus, we have only to obtain the time-series of the maximum, the minimum and the inflexional points of the observing curves as shown in Fig. 1~4. These analyses have also been processed by means of the geometrical methods ; section papers have been

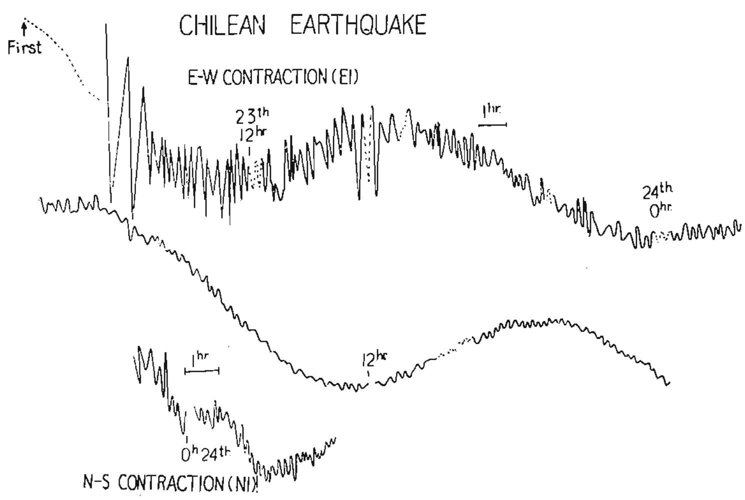

Fig. 1.

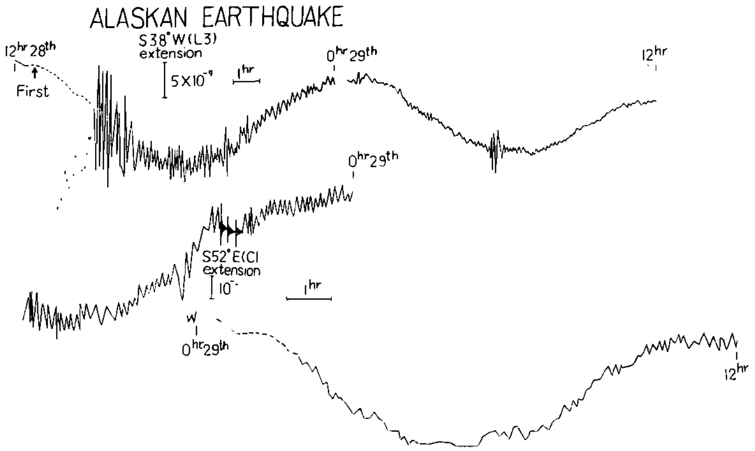
ALASKAN EARTHQUAKE
S38°W(L3)
extension
5×10⁻⁹
1hr
12hr 28th
First
0hr 29th
12hr
0hr 29th
S52°E(C1
extension
10⁻
1hr
0hr 29th
12hr

Fig. 2.

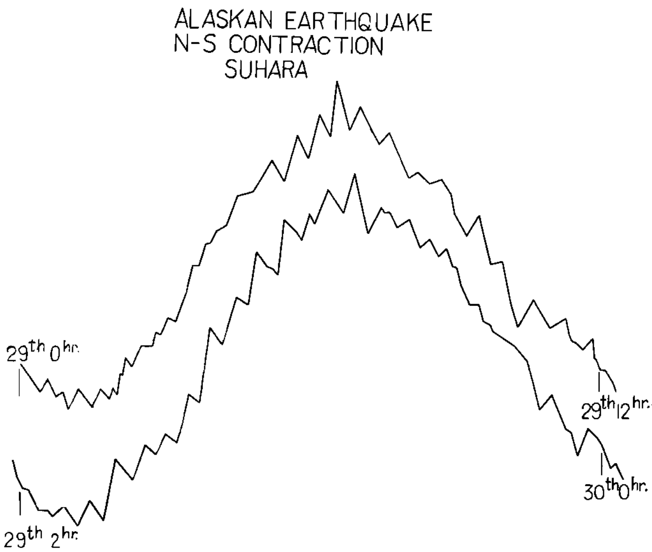
ALASKAN EARTHQUAKE
N-S CONTRACTION
SUHARA
29th 0hr.
29th 12hr.
30th 0hr.
29th 2hr.

Fig. 3.

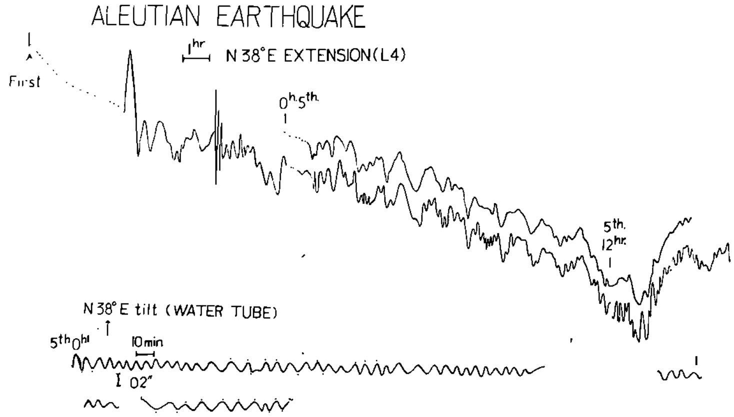
ALEUTIAN EARTHQUAKE
First
1hr
N 38°E EXTENSION(L4)
0h 5th
5th 12hr
N 38°E tilt (WATER TUBE)
5th 0hr
10min
0.2"

Fig. 4.

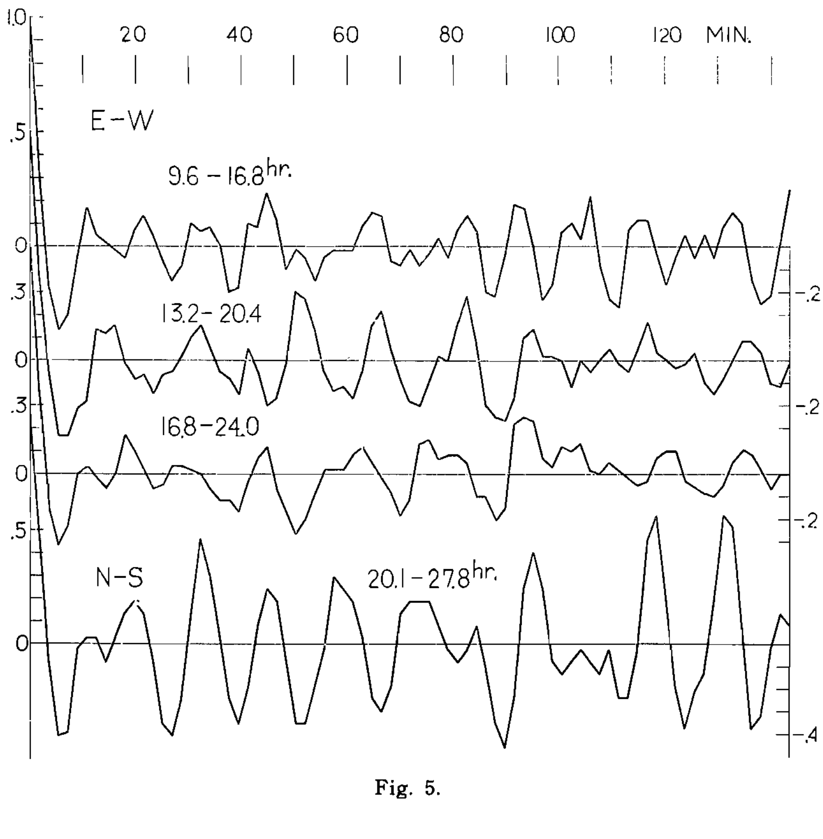
1.0
20
40
60
80
100
120 MIN.
.5
E-W
9.6 - 16.8hr
0
.3
13.2 - 20.4
0
.3
16.8-24.0
0
.5
N-S
20.1-27.8hr
0
-.2
-.2
-.2
-.4

Fig. 5.

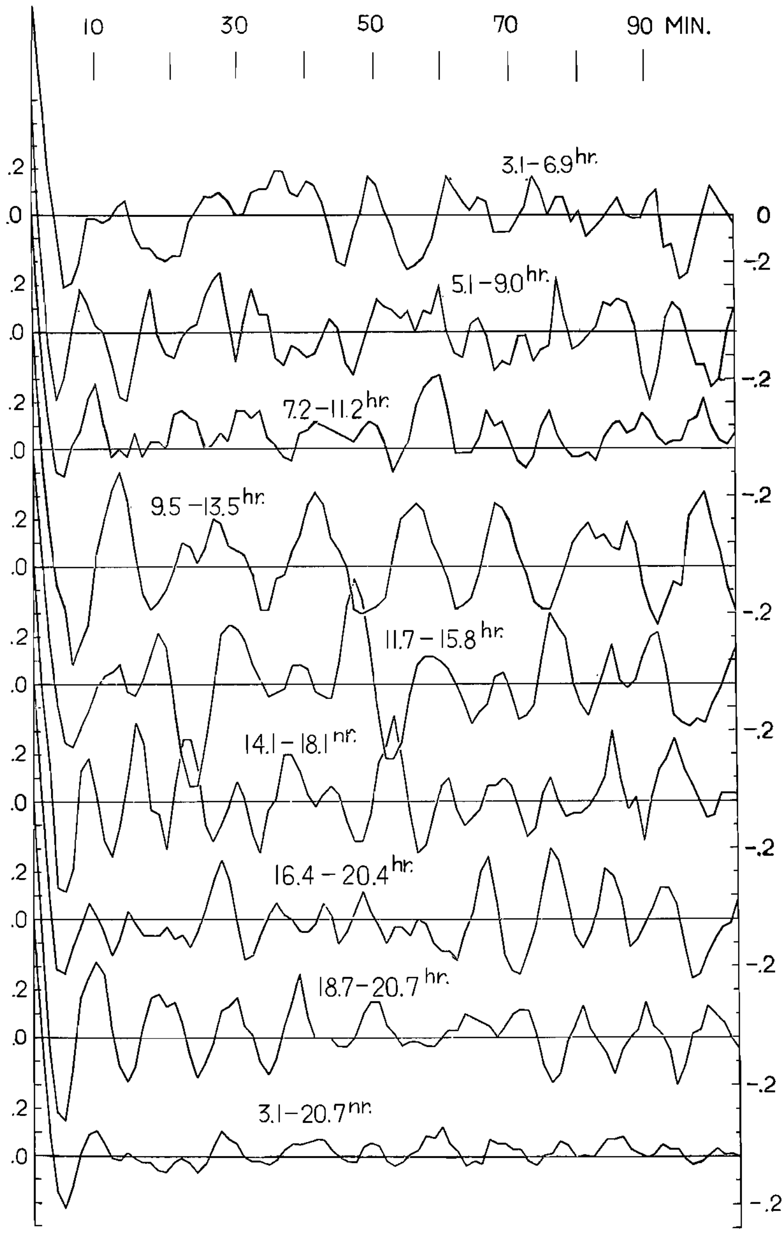
10
30
50
70
90 MIN.
3.1−6.9 hr.
5.1−9.0 hr.
7.2−11.2 hr.
9.5−13.5 hr.
11.7−15.8 hr.
14.1−18.1 hr.
16.4−20.4 hr.
18.7−20.7 hr.
3.1−20.7 hr.
.2
.0
0
−.2

Fig. 6.

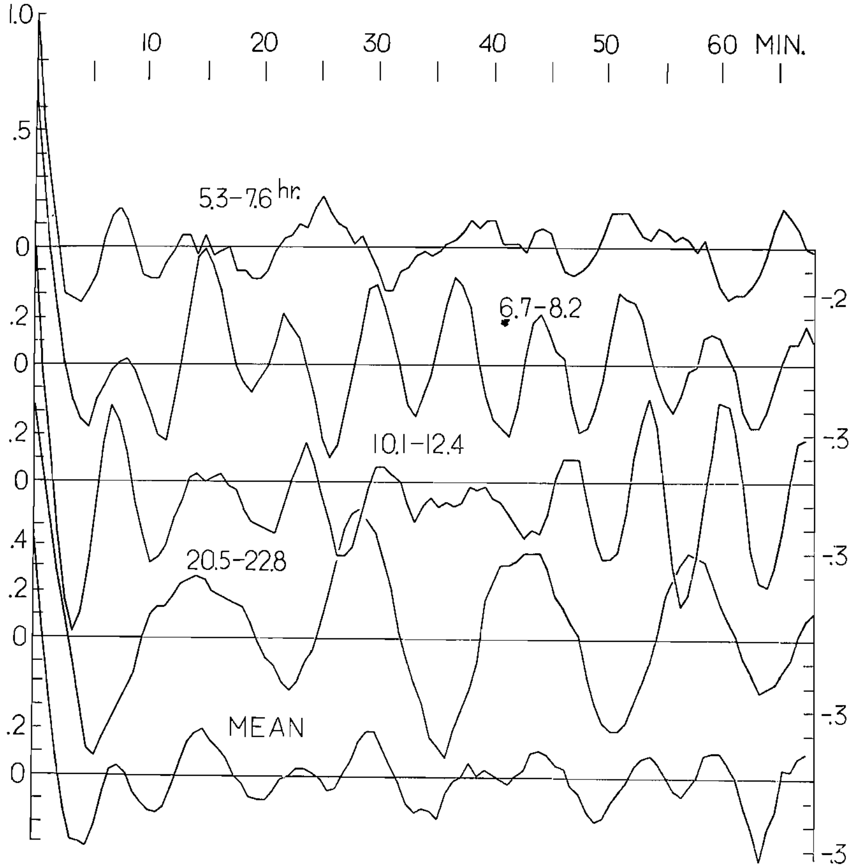
1.0
10
20
30
40
50
60 MIN.
.5
5.3−7.6 hr.
0
.2
6.7−8.2
10.1−12.4
.4
20.5−22.8
MEAN
-.2
-.3

Fig. 7.

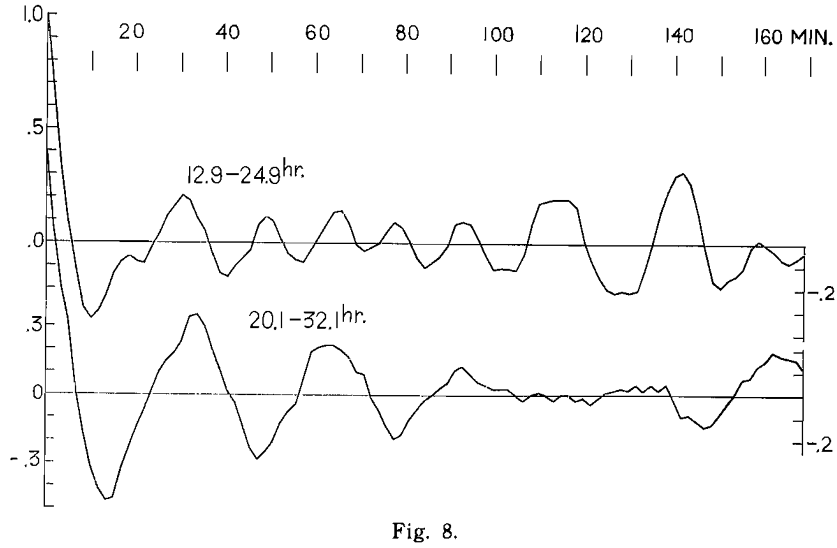
1.0
20
40
60
80
100
120
140
160 MIN.
.5
12.9−24.9hr.
.0
.3
20.1−32.1hr.
0
-.3
-.2

Fig. 8.

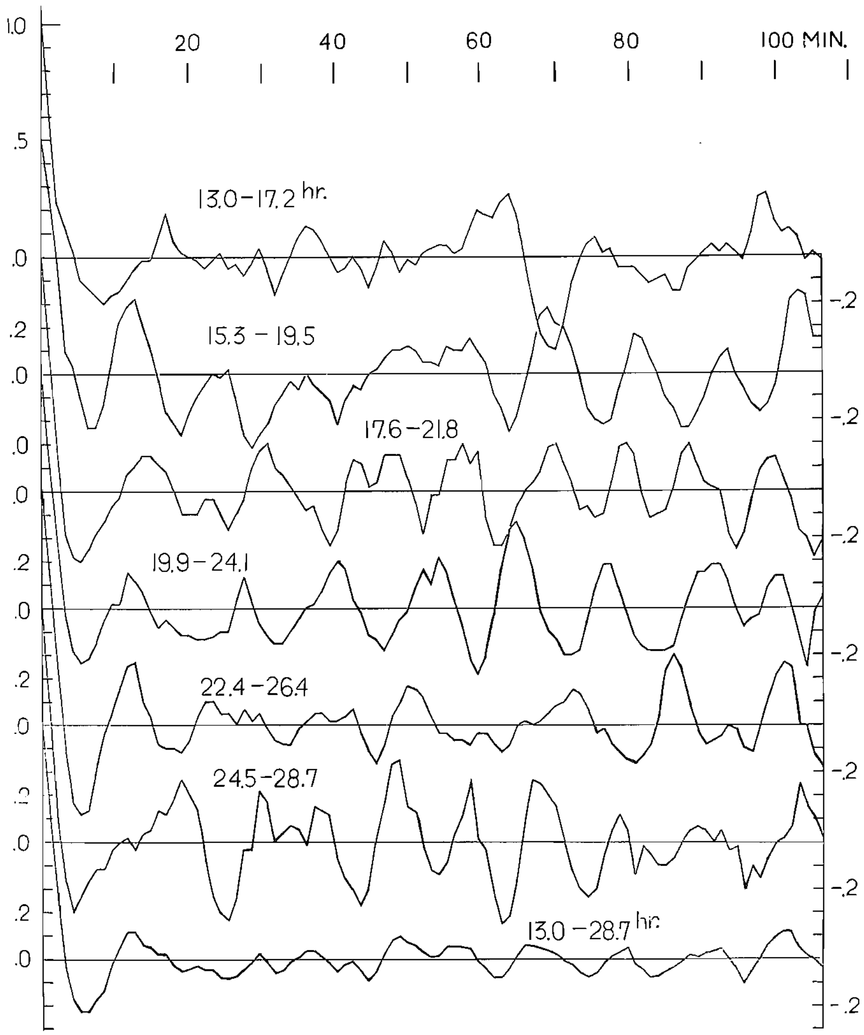
1.0
20
40
60
80
100 MIN.
.5
13.0-17.2 hr.
15.3 - 19.5
17.6-21.8
19.9-24.1
22.4-26.4
24.5-28.7
13.0-28.7 hr.
.0
.2
-.2

Fig. 9.

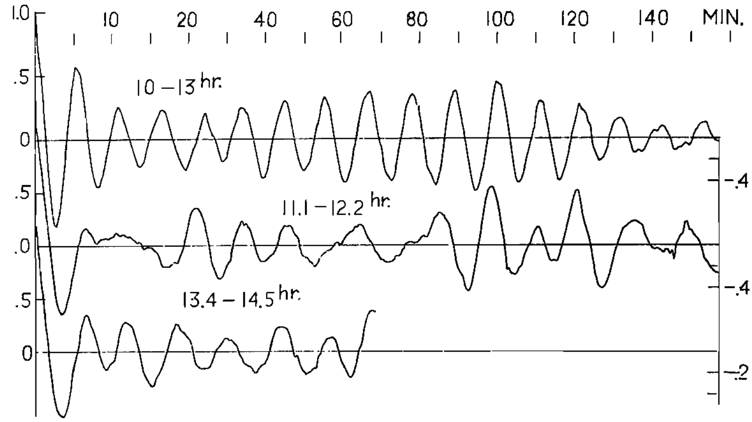

Fig. 10.

used to determine the signs of the products of any level on the series by its following level in order.

Fig. 5 shows the auto-correlation functions of the time derivative series of E-W and N-S components of the extensional curves at Osakayama in the Chilean Earthquake. Fig. 6 and 7 show those of S 38°W-N 38°E and S 52°E-N 52°W at Osakayama in the Alaskan Earthquake, respectively. Fig. 8 shows that of N-S component at Suhara in the Alaskan Earthquake. Fig. 9 shows that of N 38°E-S 38°W at Osakayama in the Aleutian Earthquake. Fig. 10 shows that of the time derivative of the tilt-oscillation of N 38°E direction component at Osakayama in the Aleutian Earthquake.

According to these results, one of the most dominant period is about ten minutes in these extensional curves and is about six minutes in the inclinational curve. It seems that these periods are different in every earthquake whose epicentral distances and azimuths of the seismic paths are considerably different. And also its period seems to change with the lapse of time like that[9] of the seismogram. For example, the dominant period of the tilt-oscillation is about 5.3 minutes in time between 1.0 and 2.0 a. m. February 4, 1965 (between 13 hr. and 14 hr. after the start motion of the Aleutian Earthquake), then, it becomes longer to 5.7 minutes in the time between 2.0 and 3.0 a. m., and it extends to 6.5 minutes in the time between 3.0 and 4.0 a. m..

Moreover, the some of the power spectra have been calculated by means of the Fourier analyses from these auto-correlation function, and they are shown as Table 4.

6. Summary.

We have observed the free oscillations of the earth in the Chilean, the Alaskan and the Aleutian Earthquakes with extensometers which had been devised by I. Ozawa and with water-tube tiltmeter which had been made by T. Eto. One of the authors (I. Ozawa) has made these observations. According to his analyses, about ten minutes period's oscillation is dominant in the records of the extensometers and about six minutes one is dominant in that

TABLE 3.
Power Spectra for Chilean, Alaskan and Aleutian Earthquake at Osakayama.

Component	E-W Extension (E_1)		S38°W-N38°E Extension (L_3)		S52°E-N52°W Extension (C_1)		N38°E Tilting (Water-tube)	
Earthquake	Chilean		Alaskan		Alaskan		Aleutian	
	Period min.	Amplitude	Period min.	Amplitude	Period min.	Amplitude	Period min.	Amplitude
	215.8	590	137.1	1273	83.05	212	66.5	278
	107.8	507	68.6	1365	41.53	160	33.2	110
	71.8	404	45.7	2348	27.65	212	22.2	274
	53.9	404	34.3	1463	20.67	548	16.6	395
	43.1	439	27.40	1630	16.61	626	13.3	679
	35.95	801	22.83	1191	13.86	381	11.1	1062
	30.80	443	19.59	911	11.87	96	9.5	982
	26.93	485	17.13	931	10.39	94	8.3	1324
	23.98	332	15.23	1933	9.22	111	7.38	1558
	21.58	722	13.71	706	8.31	183	6.65	1157
	19.60	695	12.48	1582	7.55	1759	6.04	381
	17.96	1804	11.41	1456	6.92	527	5.54	903
	16.58	1209	10.56	2118	6.39	165	5.11	313
	15.40	769	9.79	1730	5.93	209	4.75	771
	14.38	941	9.15	2186	5.53	180	4.43	496
	13.34	1094	8.57	2021	5.19	134	4.16	176
	12.68	743	8.07	1994	4.88	228	3.91	343
	11.98	488	7.62	1678	4.61	267	3.69	284
	11,34	553	7.22	1084	4.37	328	3.50	227
	10.78	752	6.86	2295	4.15	213	3.33	287
	10.26	247	6.53	962	3.95	151	3.17	444
	9.80	252	6.23	1139	3.77	88	3.02	997
	9.37	334	5.96	1393	3.61	147	2.89	339
	8.98	493	5.71	947	3.46	169	2.77	175
	8.62	294	5.48	604	3.32	134	2.66	190
	8.28	335	5.27	1000	3.19	222	2.56	857
	7.98	361	5.08	1059	3.08	216	2.46	748
	7.70	307	4.89	559	2.97	242	2.37	110
	7.43	242	4.73	722	2.86	168	2.29	533
	7.18	188	4.57	787	2.77	216	2.22	200

of the water-tube tiltmeter. These periods seem to change with the laps of the time in the same curves, and they do with the azimuth and length of their seismic paths. Moreover, the some power spectra have been calculated from these auto-correlation functions.

Afterward, we will examine whether these apparently short and dominant period oscillations are caused by the superposition of the swept periods or by the existence of remarkable discontinuity in the mantle of the earth.

Acknowledgements

In conclusion, the authors wish to express our hearty thanks to Dr. K. Sassa of the emeritus professor of Kyoto University for his encouragement. We also express our thanks to the engineers of the Geophysical Institute, observers in the Suhara Observatory and in the Kishu Mine, and assistant accountants in our chair of the Geophysical Institute for their help.

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