III. Periods of Waves in Distant Earthquakes.

12. *Earthquake motion proceeding from distant origins.*—I shall here confine myself to the consideration of those distant earthquakes (Group I), whose durations varied between $\frac{3}{4}$ h and 4 hs. (See Table II [A]). The motion consists generally of several sets of waves of different periods superposed upon each other, but the successive epochs of each earthquake seems to have certain predominating periods of vibrations.

13. *The 1st preliminary tremor.*—In the 1st preliminary tremor, the motion consisted essentially of p_1'' type vibrations, superposed with p_1' type ones, the former having the average period nearly double that of the latter, as follows :—

p_1'' type. The average period, which varied between 6,7s and 12,4s, had a mean value of 8,03s.—In the two cases of eqkes Nos. 163 and 193, there were also slow undulations of periods respectively of 15,0 and 18,0s. These waves are probably of the same kind as those often occurring in the 2nd preliminary tremor.

p_1' type. The average period, which varied between 2,1s and 6,9s, had a mean value of 4,56s.—In the three cases of eqkes Nos. 44,177 and 222, there were also small quick vibrations, the mean value of whose average periods was 2,5s.

14. *The 2nd preliminary tremor.*—Here again the motion consisted essentially of vibrations, whose average period was exactly similar to that of p_1'' type in the 1st preliminary tremor and which may be termed as p_2' type waves.

p_2' type. The average period, which varied between 5,4s and 10,8s, had a mean value of 8,06s.—In only one case, eqke No. 2, were there also vibrations of an average period of 3,1s.

In 13 cases there were also traces of slow undulations, which may be distinguished as p_2'' p_2''' and p_2'''' type waves.

p_2'' type. The average period which varied between 12,5 and 16,8s, had a mean value of 14,5s.

p_2''' type. The average period, which varied between 24,6 and 27,0s, had a mean value of 25,3s.

p_2'''' type. The average period was 66s. The waves of this type occurred only in eqke No. 193.

In eqke No. 193, there were also waves of an average period of 34,5s.

15. *The principal portion.*—As may at once be remarked from the detailed analysis of the seismograms given in the next volume, the *principal portion* begins generally with a few very slow undulations, (the *initial phase*) which here shall be distinguished as p_3 type waves. Then follow in most cases, for a certain interval of time, a series of slow undulations (the *slow-period phase*), whose period is generally different from that of the p_3 type undulations, and which may be distinguished as p_4 type waves. These are again followed by comparatively quick-period waves (*the quick-period phase*), to be distinguished as p_5 type waves. The periods in the three successive epochs of the principal portion are as follows:—

p_3 type. The waves of this type may be subdivided according to the length of period into the three types of p_3' p_3'' and p_3'''.

p_3' type. The average period, which varied between 37,5s and 41,0s, had a mean value of 39,2s.

p_3'' type. The average period, which varied between 27,0s, and 32,6s, had a mean value of 29,4s.

p_3''' type. The average period, which varied between 23,7s and 25,4s, had a mean value of 24,8s.

In a single case, eqke No. 33, there were undulations of an average period from 14,3 to 16,2s. These may be regarded as being dentical with the p_2'' type waves already considered.

p_4 type. The waves of this type may again be subdivided into three types of p_4' p_4'' and p_4''', according to the length of the period:—

p_4' type. The average period, which varied between 30s and 37s, had a mean value of 32,8s.

p_4'' type. The average period, which varied between 19s and 26,6s, had a mean value of 21,6s.

p_4''' type. The average period, which varied between 11,0s and 18,2s, had a mean value of 15,8s.

p_5 type. The waves of this type may be subdivided into two types of p_5' and p_5'', as follows :—

p_5' type. The average period which varied between 13,3s and 16,5s, had a mean value of 14,5s.

p_5'' type. The average period, which varied between 7,1s and 12,1s, had a mean value of 9,61s.

16. *The principal portion.* (cont.)—In the following Table, I give $y_{3,4}$ or the duration of the time interval between the beginning of the principal portion and the first appearance of the p_5 type waves, or the *quick-period phase*, in cases of 13 large earthquakes, together with y_1 or the duration of the 1st preliminary tremor, where these durations have definitely been measured.

No. of eqke.	y_1		$y_{3,4}$	
	m	s	m	s
69	9	54	6	0
127	9	17	7	41
143	17	35	22	0
147	8	24	29	50
186	8	20	5	58
188	9	30	8	55
193	7	36	8	30
201	10	19	12	0
217	4	23	2	41
218	4	36	3	13
220	6	20	5	0
222	3	10	2	48
58	4	15	4	34
Mean.	9	10	7	58

Thus we have, on average,

$$\frac{y_1}{y_{3,4}}=0,87$$

Thus y_1 is approximately equal to $y_{3,4}$ (See § 34).

The time interval between the beginning of the principal portion and the appearance of the *slow-period phase* was generally difficult to estimate definitely, there being often cases in which there existed no *initial phase.*

17. *The end portion.*—The motion, which is to be distinguished as p_6' type, consisted mostly of regular vibrations, whose average period varied between 8,0s and 10,9s and had a mean value of 9,75s.

In five cases of eqkes Nos. 33,43,47,193 and 201, there were also slower waves, to be distinguished as p_6'' type, whose average period varied between 14,0s and 16,5s and had a mean value of 15,8s.

18. *Results summarized.*—The results obtained in the preceding § § are summarized in the following table ; the periods, which may be regarded as mutually equal, being collected in the same horizontal row.

1st Prel. tr.	2nd Prel. tr.	Principal portion.			End portion.	Mean.
		Initial phase.	Slow-per. phase.	Quick-Per.phase.		
(p_1') 4,56s	———	———	———	———	———	$P_1=4,56$
(p_1'') 8,03	(p_2') 8,06s	———	———	(p_5'') 9,61s	(p_6') 9,75s	$P_2=8,86$
———	(p_2'') 14,5	———	(p_4''') 15,8s	(p_5') 14,5	(p_6'') 15,8	$P_3=15,2$
———	———	(p_3''') 24,8s	(p_4'') 21,6	———	———	$P_4=21,6$
———	(p_2''') 25,3	(p_3'') 29,4	———	———	———	$P_5=25,1$
———	———	(p_3') 39,2	(p_4') 32,8	———	———	$P_6=31,1$
———	———	———	———	———	———	$P_7=39,2$
———	(p_2'''') 66,0	———	———	———	———	$P_8=66,0$

P_1 P_2.....P_7 P_8 denote the means of the periods in the different rows. The figures in the above table may be regarded as representing the periods most likely to occur in the different epochs of distant earthquakes. There probably exist a series of periods between the

values of P_7 and P_8, which must be discovered by further observations. Some of the points to be noted are the following.

1.—p_1'' in the 1st preliminary tremor and p_2' in the 2nd preliminary tremor are identical, giving the mean value of 8,05s.

2.—p_5'' in the quick-period phase of the principal portion and p_6' in the end portion are identical, giving the mean result of 9,68s.

3.—p_2'' of the 2nd preliminary tremor, p_4''' and p_5' of the principal portion, and p_6'' of the end portion are identical.

4.—p_2''' of the 2nd preliminary tremor and p_3''' of the principal portion are identical.

5.—p_3'' and p_4' of the principal portion are identical.

The six periods P_1 P_2 P_3 P_4 P_5 and P_6 form roughly a series of an arithmetical progression, the mean common difference being 5,0s.

19. *The periods of vibration in the 1st and 2nd preliminary tremors and in the end portion.*—It will be observed that the periods of vibration in the 1st and 2nd preliminary tremors and in the end portion of different earthquakes are nearly constant, and further that their mean value, P_1, is nearly equal to the limiting value of 8,0s of the average period of *pulsatory oscillations*. This may probably be explained on the assumption that different portions of the earth's crust have particular periods of free oscillations, as discussed again in the case of *pulsatory oscillations* (§ 31). Such a supposition fits particularly well in the case of the vibrations in the end portion ; since the duration of an earthquake is long and the ground must be executing wave motion for a considerable time interval after the original impetus, which caused the seismic disturbance, has ceased. This is quite analogous to the motion of sea waters, the diagrams from tide-

guages showing constant periods proper to different places of observation.*

20. *Remarks on the period of the earthquake motion.*—The average period in distant earthquakes remains constant throughout the end portion. Within certain limits, the period of the different types P_1 P_2 .....P_8 may depend on the distance between the earthquake origin and the place of observation. This and other questions shall be discussed on another occasion, but in the meanwhile I may state that long-period undulations also exist in earthquakes of near origin. Thus, for instance, in the Kiushiu earthquakes, Nos. 236 and 237, the periods of 31,3 to 35,4s were recorded in Tokyo. Different kinds of waves are probably originated simultaneously at the seismic origin, but quick-period vibrations are soon dissipated in consequence of the viscosity of the material forming the earth's crust, while slow undulations are less subject to such a dissipation and travel to great distances.

IV. On the Nature of the Long-Period Undulations of Earthquakes.

21. About two years ago I expressed the view that the slow-period undulations of great earthquakes are probably *horizontal*, and not tilting, movements.† This supposition was based on the fact that, in the earthquake of Nov. 7th, 1898, the range of motion was equally large in the diagrams from two different horizontal pendulum apparatus, both in the E W direction, which ought to have been differently sensitive to the tilting of the ground, if any.

Recently I have observed a number of earthquakes simultaneous-

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* See Vol. XXXIV of the Reports (Japanese) of the Earthquake Investigation Committee in which the present writer discusses in detail the tide gange diagrams at different places in Japan, in reference to the causes of sea-waves.

† Jour. Coll. Sc. Imp. Univ. Tokyo. Vol. XI. 1899.