$$t_0 = t_1 - 1.232\ y_1 \ \ldots\ldots\ldots (2)$$

For the purpose of practical application, however, it seems better to adopt the ratio of $v_1 : v_2$ obtained by the "direct method"; the formula then becomes

$$\boldsymbol{t_0 = t_1 - 1.151\ y_1} \ \ldots\ldots\ldots (3)$$

Equation (3) does not much differ from one previously given.

149. ***Remarks on the Methods of Velocity Calculation.*** In all the velocity calculations by the "direct method" given in the preceding Chapters, the times of occurrence of the different phases of the earthquake motion at a given station have been compared with the time (t_0) at the origin of disturbance. This is equivalent to assuming that at the latter there existed no preliminary tremor; in other words, that the various sets of vibrations composing the seismic motion were generated simultaneously at the centre. I believe this supposition is generally legitimate, although there is possibility, especially in cases of large earthquakes, of slight premonitary shakings apart from the usual preliminary tremors.

Chapter X. Miscellaneous Remarks.

150. ***Notes on the Tokgo Observations.*** The following remarks on the Tokyo observations are based on the analysis of the seismograms of the Kangra earthquake given in §§ 13 to 21.

151. *Small movements of Sensible or Macro-seismic Character.* The Hitotsubashi diagram furnished by a horizontal pendulum of 8 times magnification indicated in the 1st preliminary tremor small vibrations, whose average period was 0.71 sec. These movements were evidently of the character of macro-seismic or sensible motion, their period being nearly equal to that most frequently occurring in ordinary earthquake shocks observed at Hitotsubashi.* The occurrence in distant earthquakes of quick vibrations, whose period is about 1 sec., is not very rare † From the observations like the above we may conclude :

(i) That *a great earthquake disturbance may give rise to small vibrations of macro-seismic character at a considerably distant place, especially when the soil at the latter is soft.* It is a movement of this sort which starts the electric contact-maker of an ordinary Ewing or Gray-Milne seismograph at a far-off station ; those large vibrations in the 2nd preliminary tremor or the different phases of the principal portion are quite inadequate to affect a macro-seismograph on account of the length of the period, their acceleration of motion of the earth's particle being a very small quantity.

(ii) That *the principal period of the macro-seismic vibration at Hitotsubashi is practically constant and independent of the earthquake cause or of the epicentral distance.* This inference, which probably holds good for any other place where the ground is soft, may be accounted for by assuming that the earthquake vibrations at a place are essentially composed of the proper oscillations of the ground characteristic to the region in question ;‡ well defined vibrations at the commencement of the different phases of the motion being excepted.

152. *Pulsatory Oscillations.* Both before and after the Kangra earthquake there existed very small pulsatory oscillations, which

* See the *Publications,* No. 11 and No. 13.
† The *Publications,* No. 13.
‡ See the *Publications,* No. 11 and No. 13.

were clearly recorded by the tromometers, and which belonged to the Q_1 class motion,* their average period being 4.1 sec. By the way, it may be remarked that the period of these pulsatory oscillations was identical at the University Compound (Hongo) and at the Central Meteorological Observatory, in spite of a mutual distance of 3 km, and of an entire difference in the nature of the grounds, between the two places.

Turning our attention to the P_1 motion, we find from §§ 14 to 20, that the records furnished by the different instruments were as follows :—

			T	Max. $2a$
EW COMPONENT.	§ (14) :	1st Prel. Tremor,	4.6 sec. ;	0.20 mm
	„ (20) :	„	4.4	0.25
	„ (21) :	„	4.4	0.17
	„ (18) :	„	4.6	0.35
	„ (20) :	2nd Prel. Tremor.	4.8	0.21
		Mean	**4.6** sec.	**0.24** mm
NS COMPONENT		: 1st Prel. Tremor,	5.2 „	0.14 „
VERTICAL COMPT		: „ „ ,	4.2	0.71 (?)

Comparing, for the EW component, the pulsatory oscillation (Q_1) with the earthquake vibration (P_1), we see that the amplitude of the latter was some 20 times that of the former ; the periods of the two sets of motion being, however, nearly equal to one another. This result seems to give support to the theory advanced by me some years ago that the pulsatory oscillations (Q_1 and Q_2) and the earthquake vibrations (P_1 and P_2) are essentially alike in nature, and that the latter consist in the amplification of the former, which always exist more or less at, and characterize, a given district.† For the sake of reference, I give next the periods of the pulsatory

* See the *Publications*, No. 13.

† See the *Publications*, No. 13.

oscillations on Mount Tsukuba (in the province of Hitachi, Japan), at Ishinomaki (province of Rikuzen), Osaka, and Taito (Formosa):

(i)	Mount Tsukuba* (Province of Hitachi, Japan).	Q_1:	T=about 4 sec.
(ii)	Ishinomaki.	Q_1:	T=5.2 sec., $2a$=0.05 mm.
(iii)	Taito (Formosa).	Q_1:	T=5.6 „ , $2a$=0.2 mm T=4.7 „ , $2a<0.2$ mm.
(iv)	Osaka.	Q_1:	T=5.0 sec.

The pulsatory oscillation indicated on the Batavia photogram (§ 47) had a period of 7.6 sec. and may correspond to Q_2.

153. *On the Comparison of Diagrams furnished by different instruments; existence of P_2 vibrations in the 2nd Preliminary Tremor and the Principal Portion.*

As will be seen from § § 14 and 20, the diagram given by the long-period horizontal pendulum is materially different from that given by the tromometer. Thus, the former diagram shows, in the 2nd preliminary tremor most prominently 4 sets of slow vibrations of T respectively=49.7 sec., 37.7 sec., 86.0 sec., and 26.5 sec.; the P_1 and P_2 vibrations being altogether absent or only insignificantly shown. On the other hand, the 2nd preliminary tremor in the tromometer diagram is entirely made up of 3 sets of comparatively quick movements, namely, P_1, P_2, and $P_{2,3}$ vibrations, Again, the long-period pendulum record indicated, in the 1st and 2nd phases of the principal portion, prominent vibrations of T of 27.6 to 59.0 sec.; $P_{2,3}$ vibrations being only slightly shown. In the corresponding part of the tromometer record, however, P_2 vibrations were indicated nearly to the same extent as other slower movements, whose period varied between 16.8 sec. and about 53 sec.

* The observation made with a horizontal pendulum tromometer by His Imperial Highness Prince Yamashina at his Observatory on Mount Tsukuba has proved that the pulsatory oscillation exists, though slightly, also on solid mouutain tops.

The principal cause of the great dissimilarity between the records furnished by the two instruments was evidently in the difference in the lengths of the periods of natural oscillation of the two pendulums.*

The real amplitude of the slow vibrations in the 2nd preliminary tremor and the principal portion seems, in great earthquakes, to be considerable and much greater than is shown in most seismograms; the friction between the different parts of the seismograph reducing, even when the *steady mass* has a long oscillation period, the *recorded* range of such a motion more or less.

One notable fact demonstrated by the tromometer record is that the P_2 vibrations were not confined to the 1st preliminary tremor, but also occurred prominently in the 2nd preliminary tremor and in the 1st and 2nd phases of the principal portion. It is highly probable that the P_2 vibrations exist throughout the principal portion of every large earthquake motion. (See also § 126.)

The question of the existence of P_2 vibrations in the principal portion is very important in connection with the discussion of the different periods occurring in the earthquake motion. As I have pointed out in the *Publications*, No. 13,‡ the principal period of vibration occurring in the *preliminary tremors* and the *end portion* is P_2 (some times P_1), and it would be strange, if similar movements did not occur in the intermediate phases, namely, the *principal portion*; it being quite natural to assume some existence throughout the earthquake motion of the P_1 and P_2 vibrations, which are identical to the proper Q_1 and Q_2 oscillations of the ground.

* See the *Publications*, No. 23.

‡ Published in 1901.

154. *Direction of Motion.* Confining our attention to the EW component, we see, from the analysis of the record given by the long-period instrument (§ 14), that the 1st displacement of the initial slow vibration of each of the two preliminary tremors was directed towards *W*; the 1st motion of the initial (P_1) vibration of the 1st preliminary tremor being, according to the tromometer record (§ 20), also directed towards *W*. Similar directional tendency of motion was shown more clearly in the 3rd phase of the principal portion recorded by the latter instrument, where there were a series of maximum groups, of which 4 well defined ones have been described in § 20. The amplitudes of the successive displacements of vibrations composing one of these groups were, on the average, in the following relative ratios :—

1st displ.	2nd displ.	3rd displ.	4th displ.	5th displ.	6th displ.
(E)	(W)	(E)	(W)	(E)	(W)
1.00	1.84	3.31	6.22	6.90	5.60

It will be thus seen that the 1st, 2nd, and 3rd displacements, were directed towards E, W, and E, respectively; it being the 4th and westward motion which constitutes the first and sudden large displacement.

In the NS component diagram (§ 15), the 1st displacement of the well-defined slow vibration at the commencement of the 1st preliminary tremor was directed towards N; the very initial motion of quick movements mixed with the above being also directed towards N.

155. ***Similarity with the diagrams of the Alaska earthquakes.*** The EW component Tokyo diagram of the Kangra earthquake (Pl. I, the *Publications*, No. 23) is on the whole somewhat similar to those of the Alaska earthquakes of 1899 and

1900*; the movements at the commencement of the 2nd preliminary tremor being specially alike each other. This is evidently the result due to a sort of symmetry of the positions of the origins of the two sets of earthquakes with respect to the meridian (or prime vertical) of Tokyo; the positions of the centres in question relative to the latter place being as follows:—

	Epicentral Distance of Tokyo.	Azimuth of Eqke. Origin.
Kangra Eqke.	51° 26′	W 75° 05′ 36″ (from N)
Alaska Eqkes.	55° ca.	E 40° ca.

156. *Time Difference between Tokyo and Osaka.* The times of commencement of the successive phases of motion at Tokyo and Osaka were as follows:—

TABLE LVII. Time Difference between Tokyo and Osaka.

	Phase of motion. (Commencement)	Tokyo.	Ōsaka.	Time Difference. (Tokyo—Osaka.)
		h m s	h m s	sec.
(i)	1st Prel. Tremor.	0 59 08	0 58 51	+17
(ii)	2nd „ „	1 06 46	1 06 03	**43**
(iii)	1st Phase, Princ. Portion.	1 14 24	1 13 15	69
(iv)	3rd „ , „	1 22 34	1 20 09	145
(v)	4th „ , „	1 33 49	1 30 05	224
(vi)	5th „ , „	1 42 04	1 38 05	239
(vii)	Max. Mot. in W_2.	3 39 07	3 40 56	**−109**

The arcual epicentral distances of Tokyo and Osaka are 51° 26′ and 48° 19′ respectively, and consequently the time differences between these two places (Tokyo—Osaka) were positive for the different phases of W_1 or the earthquake proper, but negative for

* See Pls. VII and VIII of the *Publications*, No. 5, and Pl. XXXVI of the *Publications*, No. 21.

the W_2 motion. It is difficult to determine exactly the instants of commencement of some of the different phases of motion, and the above time differences are only rough values, with the exception of two well defined cases of the 2nd and the last; which two relate respectively to the commencements of the 2nd preliminary tremor and the maximum vibration in the W_2 motion. Calculating from these two cases the transit velocities, we obtain the following approximate results :—

$$\begin{cases} v_2 = \dfrac{51^\circ\,26' - 48^\circ\,19'}{43^{\text{sec.}}} = 8.0 \text{ km/sec.}; \\ v'_5 = \dfrac{51^\circ\,26' - 48^\circ\,19'}{109^{\text{sec.}}} = 3.18 \quad ,, \quad . \end{cases}$$

(See also Chapter IX.)

157. ***Comparison of individual vibrations in the Tokyo and Osaka Seismograms.*** Some of the individual vibrations in the 1st and 2nd preliminary tremors can be identified with fair accuracy in the Tokyo and Osaka EW component diagrams; the times of occurrence of the corresponding movements in the two records, denoted by similar letters, *a*, *b*, *c*, *d*, ... *s*, *t*, *u*, being as in the following table. (See Pls. I and VI, the *Publications*, No. 23.)

TABLE LVIII. Comparison of the Different Vibrations in the Tokyo and Osaka EW Diagrams.

Vibration.	Tokyo.	Ōsaka.	Time Difference. (Tokyo-Osaka).
	h m s	h m s	sec.
a	0 59 08	0 58 51	17
b	0 59 36	0 59 16	20
c	1 00 05	0 59 40	25

Vibration.		Tokyo.	Ōsaka.	Time Difference. (Tokyo-Ōsaka).
1st Prel. Tremor.	*d*	1h 00m 28s	0h 59m 56s	32 sec.
	e	1 01 24	1 01 03	21
	f	1 01 36	1 01 12	24
	g	1 02 23	1 02 02	21
	h	1 06 38	1 06 03	35
2nd Prel. Tremor.	*i*	1 06 46	1 06 08	38
	j	1 07 05	1 06 18	47
	k	1 07 23	1 06 35	48
	l	1 07 55	1 06 50	65
	m	1 08 53	1 07 58	55
	n	1 09 49	1 08 49	60
	o	1 10 48	1 09 58	50
	p	1 11 07	1 10 19	48
	q	1 11 45	1 10 42	63
	r	1 12 34	1 11 25	69
	s	1 13 07	1 11 53	74
	t	1 13 40	1 12 23	77
	u	1 14 24	1 13 15	69

The identifications given in the above table indicate, on the whole, a gradual separation of the successive vibrations at the rate of about 3.93 sec. for 1 minute of the duration.

158. ***Kew, Paisley, and San Fernando Records.*** Some of the maximum movements may be identified in the seismograms at San Fernando, Kew and Paisley; these are marked by the letters *a*, *b* . . . . *m*, *n*. But the times of occurrence of these maxima at the above-mentioned 3 stations are, as given in the following table, not perfectly in accordance to the respective epicentral distances, due probably to an inaccuracy in the identifications. We can see, however, from examples like these, that the teleseismograms obtained at neighbouring places ought to be nearly identical, if not much interfered by the proper instrumental oscillations.

Max.	San Fernando.	Paisley.	Kew.	Max.	San Fernando.	Paisley.	Kew.
	h m	h m	h m		h m	h m	h m
a_1	1 16.0	1 13.2	—	g	1 51.7	1 48.6	1 45.7
a'	1 20.8	1 16.3	—	h	1 57.8	1 54.6	1 —
a	1 29.0	1 26.7	1 25.4	i	2 1.5	1 59.0	1 53.0
b'	1 31.7	1 29.0	1 27.3	j	2 7.0	2 5.8	1 56.5
b	1 33.8	1 31.4	1 28.9	k	2 14.5	2 12.8	2 7.6
c	1 36.7	1 34.4	1 32.6	l	2 20.4	2 17.9	2 13.7
d	1 39.0	1 36.4	1 35.5	m	2 27.6	2 30.4	2 22.0
e	1 42.5	1 39.8	1 37.7	n	2 35.7	2 38.5	2 31.0
f	1 45.5	1 43.9	1 40.4				

159. ***Vibrations of Short Periods.*** The periods shorter than P_1 observed at some of the different stations were as follows:—

(i) Hitotsubashi (Tokyo): $T=0.71$ sec.
(ii) Hongō „ : „ $=2.2$ „
(iii) Taihoku : „ $=1.07$ „ ; $T=2.1$ sec.
(iv) Batavia : „ $=1.4$ „
(v) Manila : „ $=2.6$ „ (pendulum oscillation.)
(vi) Göttingen : „ $=2.2$ „
(vii) Upsala : „ $=2.5$ „

The vibrations corresponding to these periods were always very small. As already stated in § 150, (i) is the same as the period of the motion on the occasion of ordinary shocks observed in the low soft part of Tokyo. The periods of 1.07 sec. at Taihoku (iii), and of 1.4 sec. at Batavia (iv), also characterize the movements of macroseimic nature. The semi-macroseismic periods observed at Hongō (ii), Taihoku (iii), Göttingen (vi), and Upsala (vii), varied between 2.1 and 2.5 sec., giving the average value of $2\frac{1}{4}$ sec. This is approximately equivalent to $\frac{1}{2}P_1$.

160. ***Durations of the Successive Sections of the Earthquake Motion.*** Let the durations of the 1st and 2nd preliminary tremors, and the 1st, 2nd, 3rd, and 4th phases of the principal portion be respectively denoted by y_1, y_2, $y_{3,4}$, y_5, and y_6; the 1st and 2nd phases of the latter portion being taken together. The values of the y's observed at the 15 different stations on the occasion of the Kangra earthquake are given in Table LIX; the stations being divided into two groups (I) and (II), according to their epicentral distances. An *asterisk* suffixed to the name of a station signifies that the respective durations have been deduced by taking the means from more than one seismogram.

TABLE LIX. Durations of the Successive Sections of the Earthquake Motion.

	Station.	1st Prel. Tremor. (y_1)	2nd Prel. Tremor. (y_2)	1st & 2nd Ph., Princ. Port. ($y_{3,4}$)	3rd Phase, Princ. Port. (y_5)	4th Phase, Princ. Port. (y_6)
I	Tokyo.*	7 17 m s	7 42 m s	7 19 m s	8 50 m s	—
	Osaka.	7 12	6 55	6 54	9 56	8 00
	Tadotsu.	7 00	7 42	5 21	6 30	6 00
	Taihoku.	6 06	5 25	4 35	5 30	—
	Taichu.	6 14	5 10	4 50	5 40	—
	Birmingham.	8 21	7 37	8 49	9 30	6 21

Station.	1st Prel. Tremor. (y_1)	2nd Prel. Tremor. (y_2)	1st & 2nd Ph., Princ. Port. ($y_{3,4}$)	3rd Phase, Princ. Port. (y_5)	4th Phase, Princ. Port. (y_6)
I { Quarto-Castello, Querce, Ximeniano.	$7^m 15^s$	(15^m	09^s)	$8^m 15^s$	—
Göttingen.	7 17	$7^m 40^s$	$6^m 35^s$	5 55	5 35
Leipzig.*	7 06	7 37	6 28	7 45	5 23
Manila.	6 38	5 10	6 10	—	—
Mean.	**7 03**	**6 56**	**6 26**	**7 41**	**6 07**
II { Washington.	15 02	12 09	12 41	22 50	—
Cheltenham.*	14 44	12 15	14 39	11 31	11 20
Tacubaya.	16 38	15 42	18 04	14 52	—
Mean.	**15 17**	**13 05**	**15 46**	**15 11**	**11 20**

Thus it will be seen that the durations of the successive sections of the earthquake motion are, for each group of the stations, roughly equal to one another. The relative durations expressed in percentage numbers are given in the following table; the means deduced from the two groups (I) and (II), supposing their weights to be 2 : 1, being $y_1=100$, $y_2=94$, $y_{3,4}=95$, $y_5=106$, $y_6=83$.

TABLE LX. Relative Durations of the Successive Sections of the Teleseismic Motion.

Group.	y_1	y_2	$y_{3,4}$	y_5	y_6
I.	100	98	91	109	87
II.	100	86	103	99	74
Mean.	**100**	**94**	**95**	**106**	**83**
Table III, § 8.	100	95	79	91	95
General average.	**100**	**95**	**87**	**99**	**89**

For the sake of reference, I have also given in the above table the relative durations in question based on the previous observations made in Tokyo (§ 8). The general average values obtained by combining these with the means of the two groups (I) and (II) are as follows : y_1=**100**, y_2=**95**, $y_{3,4}$=**87**, y_5=**99**, y_6=**89**. Table III (§ 8) gives the durations for the two more succeeding sections.

161. ***Wave-length of the Earthquake Motion.*** The wave-length (L) of the quickest and slowest teleseimic vibrations, whose periods are respectively P_1 and P_{19} and which occur in the 1st and 2nd preliminary tremors, are as follows :—

1st Prel. Tremor.......$L=P_1 \times v_1=4.3\times 11.36=$ 49 km;
2nd „ „ ....$L=P_{19}\times v_2=86\times$ 6.41$=$556 „ .

For the predominating vibrations in the 3rd phase of the principal portion, we have :—

$$L=P_5\times v_2=20.4\times 3.28=67 \text{ km}.$$

Thus it seems that the vibrations composing the teleseismic motion have each a long wave-length, ranging from about 50 km to over 500 km. Hence it is to be concluded that such earthquake motion does not vary according to the contour or nature of the ground within a limited area. On many occasions, I have obtained similar diagrams with the horizontal pendulums of different constructions at Hongō and Hitotsubashi, although at the former place the ground is high and hard, while at the latter it is low and very soft. It is probable that, had the instruments at Tokyo and Osaka been exactly identical in construction and adjustments, the diagrams of the Kangra earthquake at these two places would have been almost perfectly similar to each other. Notwithstanding the differences in the instruments, the seismograms at Tokyo and Osaka were so far alike, that the individual corresponding vibrations have in many cases, been identified. Conversely, it many be supposed that earthquakes originating at neighbouring centres would give, in general, similar diagrams at a given observing station. This has been verified in the cases of many teleseismic, as well as, macroseismic, or sensible earthquake motion observed in Tokyo.*

Quick Vibrations. Small quick vibrations of macroseismic nature occurring in the teleseismic disturbance seem, unlike the slow movements, to depend on the nature of the ground, and are probably to be regarded as the secondary effect of the microseismic or pulsatory movements.

162. ***Nature of the Two Preliminary Tremors.*** It is generally recognized that the 1st and 2nd preliminary tremors of the *teleseismic motion* belong to the "longitudinal" and the "transverse" waves respectively. It is, however, not clear why the transverse vibration is in these cases always much greater than the longitudinal. The diagrams of the Kangra earthquake also indicate, in general, the same relation of the two preliminary tremors.

(i) *Mexico and America.* According to Table II (§ 8), Tacubaya is almost to the due north of the origin, and from the seismograms (Pl. X, the *Publications*, No. 23) we see that in the NS or longitudinal component, the vibrations in the 1st preliminary tremor was more distinct than in the EW or transverse component. The movements of the NS component were, however, less prominent than those of the EW, in the 2nd preliminary tremor and the 1st and 2nd phases of the principal portion; on the contrary,

* See the *Publications*, No. 21.

the NS component being much larger than the EW in the 3rd and 4th phases of principal portion and in the W_2 motion.

The Cheltenham records do not markedly indicate the directional peculiarity, except that the 3rd phase of the principal portion is much greater in the NS (longitudinal) component than in the EW (transverse).

(ii) *Central Europe.* Of the Central Europe stations, whose EW and NS components approximately or very nearly corresponded to the longitudinal and transverse vibrations, Potsdam and Göttingen show very clearly the following characteristics:—

(*a*) In the 1st Preliminary Tremor, EW motion was much greater than the NS motion.

(*b*) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was much smaller than the NS motion.

(*c*) In the 3rd Phase of the Principal Portion, the EW motion was greater than the NS motion.

(*d*) W_2....EW motion was much greater than NS motion.

Again, the 4 other stations of Quarto-Castello, Leipzig, O'Gyalla, and Ischia,* show the following characteristics:—

(*a*) In the 1st Preliminary Tremor, the EW motion was greater than the NS motion.

(*b*) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was much smaller than the NS motion.

(*c*) The NS Component motion was, except for Ischia, on the whole greater than the EW component motion.

(*d*) 3rd and 4th Phases of Principal Portion......At Ischia, the EW motion was much greater than the NS motion.

* The copies of the seismograms obtained at these 4 stations were not long enough to enable me to identify the W_2 motion.

(iii) *Japan.* The seismograms obtained at Tokyo, Osaka and Kobe, whose EW and NS components approximately correspond to the longitudinal and transverse vibrations respectively, show the following characteristics :—

(*a*) In the 1st Preliminary Tremor, the EW motion was greater than the NS motion.

(*b*) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was smaller than NS motion.

(*c*) In the 3rd and 4th Phases, Principal Portion, the EW motion was greater than the NS motion.

(*d*) W_2........EW motion was greater than NS motion.

Summary. Although the interference of the proper instrumental oscillations makes it often very difficult to form a correct comparison of the vibration amplitudes between the different seismograms, we may conclude from what was stated above provisionally as follows :—In the preliminary tremor and the 3rd and 4th phases of the principal portion, as well as the principal part of the W_2 motion, the longitudinal vibrations predominate more than the transverse; while in the 2nd preliminary tremor and the 1st and 2nd phases of the principal portion, the transverse vibrations predominate more than the longitudinal.* The difference in the magnitude of motion between the two component wave vibrations seem to depend, in the cases of the 1st and 2nd preliminary tremors, and the 1st and 2nd phases of the principal portion, chiefly on the predominance or comparative absence of slow movements.

* In this connection, the reader is referred to Dr. Imamura's paper : "Note on the Direction and Magnitude of the vibrations in the Different Phases of the Earthquake Motion.' The *Bulletin,* Vol. I, No. 3.

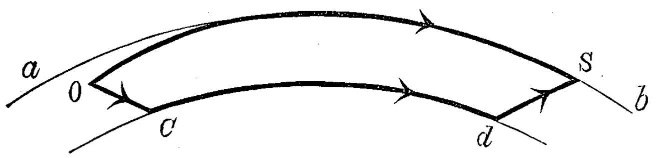
Of the sections later than the 3rd phase of the principal portion, the 8th, or the commencement of the end portion seems to be due to the transverse motion. (See the *Publications*, No. 13.)

163. ***Paths of Earthquake Propagation.*** That the vibrations of the 3rd, and in many cases strongest, phase of the principal portion are propagated along the earth's surface seems to be evident, their transit velocity being the same as that of the ordinary macroseismic or sensible earthquake motion of near origin. It thus seems that the principal energy of the earthquake shock is propagated not through the earth's interior. the observations having shown so far no positive instance of such seismic transmission to places at a considerable distance from the origin of disturbance. In the case of the Kangra earthquake, the furthest station was Tacubaya, whose epicentral arcual distance was a little more than $\frac{1}{3}$ of the whole earth's circumference; the different velocities for Tacubaya, however, not showing an evidence of the internal direct transmisson. The improbability of the chord hypothesis has already been pointed out in § 118.

As regards the preliminary tremors, I have stated in the *Publications*, No. 5, a supposition that the disturbances with the transit velocity v_1 probably travels parallel to the earth's surface at some constant depth, the formation of the small vibrations in the 1st preliminary tremor being explained as follows:—A small part of the seismic energy communicated in a downward direction at the origin causes some feeble shaking to be propagated towards the earth's interior. Such a disturbance travels with a high velocity of over 10 km/sec., along a layer some depth below the surface, and would constitute a progressive source of stress and give a sort of impetus to the upper layer of the earth's crust in a given region; the latter being consequently thrown into its own proper oscillations of periods P_1, P_2, etc.

The layer here considered may be supposed as marking the limit beyond which, the seismic waves are, on account of some physical properties of the underlying medium, unable to penetrate.*

Fig. 20.



ab....Earth's Surface.
cd....Path of 1st Prel. Tremor Vibrations.
o ....Eqke Centre.
s ....Observing Station.

One method of expalaining the discrepancy between the velocities calculated by the "direct method" and the corresponding values calculated by the "difference method" is to suppose the layer in the above hypothesis to be tolerably deep. Dr. Imamura thinks, as results of his studies in this connection, the depth of the layer in question to be several hundred kilometres.‡ Diagrammatically the paths of the vibrations of the 1st preliminary tremor and the 3rd phase of the principal portion would be respectively somewhat like *ocds* and *os* in Fig. 20.

164. ***Conclusion.*** There are many points to be discussed in connection with the teleseismic motion, which have not been touched upon in the foregoing pages. A comparison of the observations of the Kangra earthquake with those relating to the Assam and Bengal earthquake of 1897 and other large recent earthquakes is reserved for a future occasion. Whether the comparatively low transit velocities of the Kangra earthquake were connected with the continental origin requires further studies.

* Prof. H. Nagaoka has proposed a theory of the layer, along which the propagation velocity is maximum. See the *Publications*, No. 4.

‡ A. Imamura: "On the Transit velocity of the Earthquake motion originating at a near distance." The *Publications*, No. 18.