suddenly large and continued very active for $8^m\,42^s$. During the next $9^m\,42^s$, it consisted of a number of separate maximum groups. Thereafter the motion gradually diminished.

The identification of W_2 and W_3 is doubtful.

84. ***Honolulu,*** T.H.* (Observer, S.A. Deel. Compiler, A.E. Burbank.)

Commencement	$1^h\,04.^m6$
2nd Group	1 08. 7
Long Waves	1 15. 0
Maximum	1 35. 2 (2.5 mm)
	1 47. 2 (4.5 „)
	1 55. 5 (8.2 „)
End	5 20. 0

Chapter IV. Velocity of Propagation of the 1st Preliminary Tremor.

85. ***Places situated approximately on Same Great Circles of the Earth passing through the Origin of the Earthquake.***

The origin of the earthquake under consideration is situated among the great Himalayan mountain range, in the middle of the extensive continent of Asia. A question which naturally presents itself in connection with the transit velocity is whether or not the latter differed along the various routs of radial propagation. With a view of finding out such a relation, if possible, I have divided the different observing stations into a number of groups, as follows.

Group 1. Tacubaya, Toronto, Victoria, B.C., Colaba, (Bombay),

* Reproduced from Professor Milne's Circular, No. 13.

Kodaikanal (*Madras*). The great circle connecting Tacubaya with the earthquake origin passes very nearly through the North Pole; the seismic waves being propagated through the *flat regions* of Siberia and Canada and the depressed tract forming the Arctic basin. The azimuth of Tacubaya with respect to the origin, or the direction of the above mentioned great circle at the latter, is N 4°36′ W.

Toronto and Victoria, B.C., are situated slightly out of the same circle. Colaba (Bombay) and Kodaikanal (Madras) lie nearly on the southern prolongation of the meridian through the origin.

Group 2. Great Britain, North Germany, Batavia. Great Britain and North Germany lie approximately on a great circle passing through the origin, the seismic waves reaching these places after traversing through the *flat grounds* of the Transcaspian and South Russian districts. The stations belonging to this group are as follows.

Great Britain :—Kew, Edinburgh, Birmingham, Shide, Liverpool, Paisley.

North Germany :—Hamburg, Potsdam, Leipzig, Göttingen, Jena. Batavia lies nearly on the southern prolongation of the same great circle.

Group 3. South Austro-Hungary, North Italy; Nicolajew; Calcutta, Taungoo, Christchurch and Wellington (*New Zealand*); *Rio de Janeiro; Ponta Delgada* (*Azores*); *Taschkent, Tiflis.* South Austro-Hungary and North Italy lie nearly on the same great circle through the origin, which coinsides with the Caucasus Range; the paths of the earthquake propagation being in this case through *mountainous regions.* Azores, Tiflis, and Taschkent are also not much away from the same circle, while Calcutta, Taungoo (Burma), New Zealand, and Rio de Janeiro are roughly on the south-eastern prolongation of the latter.

Group 4. Taschkent, Krakau, Strassburg, Calcutta.

Group 5. Taschkent, Jurjew (Dorpat), Upsala; Porto Rico; Batavia. The great circles on which the stations of these two groups are situated are not far from those for the 2nd and 3rd groups.

Group 6. Japan. The seismic waves reached Japan by paths across plateau and continent, the great circle connecting the origin with Tokyo passing through Tibet, the valley of the Hoang Ho, southern extremity of Korea, and the western part of the Main Island of Japan. The stations of this group are :— Tokyo, Mizusawa, Kobe, Osaka, and Taihoku.

Group 7. Tiflis; Belgrade; Ischia, Messina; Querce, Ximeniano, Quarto-Castello (Florence); Rocca di papa; San Fernando; Calcutta, Taungoo; Wellington, Christchurch (New Zealand). All these places are situated approximately on one and the same great circle; the first 9 being towards WNW, and the remaining 4 towards ESE, of the earthquake origin.

Group 8. Washington, Cheltenham, Toronto, Tiflis; Kodaikanal, Batavia. All these places are approximately on one and the same great circle through the origin, the first 4 being to the NNW, and the remaining 2 to the SSE, of the latter.

Group 9. Honolulu (Hawaii), Irkutsk.

Group 10. Formosa, Bairût (Asia Minor).

Single Stations. Those places which do not make groups lying on a great circle through the origin are as follows :—Manila, Mauritius, Cape Town, Baltimore.

86. *Methods of Calculating the Velocities of Earthquake Propagation.* * There are two distinct methods of the velocity calculation, as follows :—

(A) "Direct Method," in which the transit velocity is obtained

* See the *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. 1.

by dividing the epicentral distance of a station by the difference between the times of occurrence of a particular phase of motion at the latter and the origin of disturbance. Thus, if x' be the epicentral distance of a place, and t' and t_0 be respectively the times of occurrence at the latter and the origin, we have :—

$$\text{Velocity} = \frac{x'}{t' - t_0}.$$

(B) "Difference Method," in which the velocity is obtained by dividing the difference of the epicentral distances of any two stations by the difference of the times of occurrence of a given phase of motion at these stations. Thus, if x' and t' have the same meaning as before and if x'' and t'' be the corresponding quantities at a second place, we have :—

$$\text{Velocity} = \frac{x' - x''}{t' - t''} = \frac{\delta x}{\delta t}.$$

The "difference method" gives always a higher value of the velocity than the "direct method"; the discrepancy, which becomes smaller with the increase of the epicentral distance, being markedly shown up to the distance of about 40°.

In the "difference method," we have no need of ascertaining the time of occurrence at the origin of disturbance; the inaccuracy about the position of the epicentre being also avoided in a great measure, provided those stations which are taken for combination lie on one and the same great circle passing through the epicentre, on one side of which they are all situated.

The velocities corresponding to the commencement of the different phases of the earthquake motion will be denoted in subsequent §§ by the same symbols as in my former papers, namely, as follows :—

v_1 ..... Velocity of the 1st preliminary tremor;
v_2 ..... „ 2nd „ „ ;

v_3..... Velocity of the 1st Phase, Principal Portion;
v_4..... „ 2nd „ „ ;
v_5..... „ 3rd „ „ ;
v_6..... „ 4th „ „ ;
v_7..... „ 5th „ „ ;
v_8..... „ End Portion (8th Section).

In the velocity calculations, the epicentral distance (x) has been taken to denote the *arcual* length between the earthquake origin and a given station.

I give next the values of the transit velocity v_1, for the different groups of stations, deduced according both to the "direct method" and the "difference method"; all the necessary data being contained in Table I. For the "direct method" calculation, the time of earthquake occurrence at the epicentre has been assumed to be $t_0=0^h49^m48^s$ G.M.T.

87. *Group1. Tacubaya; Toronto; Victoria, B.C.; Colaba (Bombay); Kodaikanal (Madras).*

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
				km/sec.
Tacubaya	128° 47′	$1^h11^m25^s$	21^m37^s	11.03
Toronto, Victoria, B.C.	99 36	1 06 42	16 54	10.91
Colaba	13 28	0 53 08	3 20	7.48
Kodaikanal	21 35	0 55 48	6 00	6.66

The mean transit velocity along the rout approximately *through the North Pole*, deduced from the observations at Tacubaya, Toronto, and Victoria, was, for $x=114°\ 12'$, about 10.97 km per sec. The time of commencement given by the Kodaikanal register seems to be somewhat too late.

v_1 calculated by "Difference Method."*

Combination of Stations.	δx	δt_1	v_1
Tacubaya — {Toronto / Victoria}	29° 11′	4^m43^s	11.45 km/sec.
„ — Colaba	115 19	18 17	11.68
{Toronto / Victoria} — „	86 08	13 34	11.76

The values of v_1 here obtained agree well with each other and vary between 11.45 and 11.76 km per sec., giving the average velocity of **11.63** km per sec. This is about 0.7 km greater than the value found by the "direct method," and may be regarded as the velocity of the 1st preliminary tremor when passing through the earth's crust near the *North Pole.*

88. *Group 2. Great Britain, North Germany; Batavia.*

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
Great Britain. {Shide, Kew, Paisley, Liverpool, Birmingham, Edinburgh.}	58° 54′	h m s 1 00 24	m s 10 36	km/sec. 10.30
North Germany. {Hamburg, Leipzig, Potsdam, Göttingen, Jena.}	50 50	0 58 43	8 55	10.56
Batavia.	42 35	0 58 33	8 45	9.01

As remarked below, the time given by the Batavia register seems to be a little too late. The results obtained for the two groups of the British and North German stations are practically

* Kodaikanal excluded.

identical, the mean velocity being **10.36** km per sec., for $x=54°$ 45′ The path of the earthquake propagation was, in these cases, almost entirely across flat regions.

v_1 calculated by "Difference Method."

Station.	δx	δt_1	v_1
		m s	km/sec.
Great Britain—North Germany	8° 04′	1 41	8.87
„ —Batavia	16 19	1 51	17.4 (?)
N. Germany— „	8 15	0 10	91.7 (?)

From this last table it will be seen that the Batavia time was a little too late.

89. ***Group 3. South Austro-Hungary, North Italy; Nicolajew; Calcutta, Taungoo, Christchurch and Wellington; Rio de Janeiro, Ponta Delgada (Azores), Taschkent, Tiflis.*** *

v_1 calculated by "Direct Method."*

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
South Austro-Hungary.... Laibach. Triest. Pola.	49° 42′	0 58 47	8 59	10.24
North Italy..... Querce. Ximeniano. Quarto-Castello. Padova.	51 46	0 58 51	9 03	10.63
Nicolajew.	37 20	0 58 54	9 06	7.60
Calcutta.	13 42	0 52 00	2 12	11.53

(* Time observation of Rio de Janeiro was not satisfactory, while the time of commencement given by the magnetograph at Taungoo is that corresponding to the beginning of the principal portion. These two places have, therefore, been excluded from the calculation of v_1.)

Station.	x	t_1	$t_1 - t_0$	v_1
New Zealand .... {Christchurch. Wellington.	115° 24′	h m s 1 09 54	m s 20 06	km/sec. 10.63
Ponta Delgada.	79 54	1 01 00	11 12	13.21
Taschkent.	11 20	0 52 24	2 36	8.07
Tiflis.	27 26	0 55 48	6 00	8.47

For large epicentral distances of over 50°, we obtain, by taking the means from the South Austro-Hungary, North Italy, and New Zealand stations, a velocity of **10.50** km per sec. The times given by the Calcutta and Ponta Delgada registers were evidently too early, while that for Nicolajew was a little too late.

The mean value of v_1 deduced from the first two sets of stations, namely, **10.45** km per sec., is the velocity of earthquake propagation partly along the Caucasus Range. This value is, however, practically identical with the transit velocity for the stations of Group 2, for which the path of propagation is situated across the flat grounds.

"Difference Method." The South Austro-Hungary and North Italy stations are near one another. Taking, therefore, the means from these, we obtain :—

$$x = 50°\ 44′; \qquad t_1 = 0^h\ 58^m\ 49^s$$

Combining these values with those for Calcutta, New Zealand, Ponta Delgada, Taschkent, and Tiflis, we obtain :—

Station.	δx	δt_1	v_1 "Difference Method."
Calcutta.	37° 02′	m s 6 49	km/sec. 10.06
Christchurch. Wellington.	64 40	11 06	10.80

Station.	δx	δt_1	v_1 ("Difference Method")
		m s	km/sec.
Nicolajew.	13° 24′	– 05	(?)
Ponta Delgada.	29 10	2 12	24.73
Taschkent.	39 24	6 24	11.37
Tiflis.	23 18	3 00	14.30

Here again we see that the Calcutta time was slightly too early, while the Ponta Delgada time was probably more than 2 minutes too early. The results relating to these two stations are, therefore, to be excluded from the discussion of the velocity v_1. We have further :—

Combination of Stations.	δx	δt_1	v_1
		m s	km/sec.
New Zealand-Taschkent.	104° 04′	17 30	11.01
„ -Tiflis.	87 57	14 06	11.55
Tiflis -Taschkent.	16 06	3 24	8.77

Excepting the last combination, in which the distance (x) of each station was small, we obtain the following mean value :— v_1=**11.81** km per sec.

The exceptionally high velocity of 14.30 km per sec., obtained by combining Tiflis with Austro-Hungarian and Italian stations, can not otherwise be explained than by supposing that the transit velocity between Tiflis and the origin of disturbance was comparatively low.

90. ***Group 4. Taschkent, Krakau, Strassburg; Calcutta,***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Taschkent.	11° 20′	0 52 24	2 36	8.07
Krakau.	45 30	0 58 12	8 24	10.03
Strassburg.	53 31	0 58 26	8 38	11.48
Calcutta.	13 42	0 52 00	2 12	11.53

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
		m s	km/sec.
Strassburg-Krakau.	8° 01′	0 14	63.6 (?)
„ -Taschkent.	42 11	6 02	12.95
„ -Calcutta.	39 49	6 26	11.46
Krakau-Taschkent.	34 10	5 48	10.91
„ -Calcutta.	31 48	6 12	9.50
Calcutta-Taschkent.	2 22	(-0 24)	(?)

The two above tables show that both the Strassburg and Calcutta times were somewhat too early. Rejecting, therefore, the results relating to these two places, we obtain :—

Taschkent.....v_1 (Direct Method) = 8.07 km/sec.
Krakau.....v_1 „ =10.03 „
Krakau-Taschkent...v_1 (Difference Method)=10.91 „

91. ***Group 5. Porto Rico, Batavia, Taschkent, Upsala.***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Taschkent.	11° 20′	0 52 24	2 35	8.07
Batavia.	42 35	0 58 33	8 45	9.01
Jurjew.	42 49	0 57 52	8 04	9.87
Upsala.	47 41	0 58 22	8 34	10.31
Porto Rico.	118 25	1 10 25	20 37	10.64

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
		m s	mk/sec.
(i) Porto Rico—Upsala.	70° 44′	12 03	10.87
(ii) „ —{Jurjew. Batavia.	75 43	11 52	11.82
(iii) „ —Taschkent.	107 05	18 01	11.01
(iv) Upsala —{Jurjew Batavia.	4 59	00 09	61.5 (?)
(v) „ —Taschkent.	36 21	5 58	11.28
(vi) {Jurjew Batavia} — „	31 22	5 49	9.99

Excluding (iv), we get the following mean values :—

$\delta x = 84°\ 31′, \ldots\ldots v_1 = 11.23$ km/sec.
$\delta x = 33\ \ 52, \ldots\ldots v_1 = 10.64$ „

92. ***Group 6. Japan :—Tokyo, Mizusawa ; Kobe, Osaka, Tadotsu ; Taihoku.*** The time of commemcement at Tadotsu is slightly doubtful, owing to some indistinctness in the time-marking, and is, therefore, excluded in the following calculation of v_1.

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Tokyo, Mizusawa.	51° 33′	0 59 11	9 23	10.17
Osaka, Kobe.	48 11	0 58 39	8 51	10.08
Taihoku.	39 27	0 57 19	7 31	9.72

Taking together the 4 stations of Tokyo, Mizusawa, Osaka, and Kobe, we obtain :—v_1=**10.13** km/sec.

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
		m s	km/sec.
Tokyo, Mizusawa—Osaka, Koke.	3° 22′	0 32	11.69
„ —Taihoku.	12 06	1 52	12.00
Osaka, Kobe — „	8 44	1 20	12.11

The average value of v_1 deduced from the above 3 combinations is **11.93** km per sec,

93. ***Group 7. Tiflis; Belgrade; Ischia, Messina; Querce, Ximeniano, Quarto-Castello (Florence); Rocca di papa; San Fernando; Calcutta, Taungoo*; Wellington, Christchurch (New Zealand).***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Tiflis.	27° 26′	0 55 48	6 00	8.47
Belgrade.	45 29	0 57 47	7 59	10.55

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Ischia, Messina.	50° 08′	0 58 58	9 10	10.13
Querce, Ximeniano, Quarto-Castello, Rocca di papa.....	51 45	0 58 55	9 07	10.61
San Fernando.	66 47	1 02 30	12 42	9.74
Wellington, Christchurch.	115 24	1 09 54	20 06	10.63

The 7 stations of Belgrade, Ischia, Messina, Querce, Ximeniano, Quarto-Castello, and Rocca di papa, give the following means :— $x=50°\ 27'$; $v=10.46$ km/sec.

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
		m s	km/sec.
Wellington, Christchurch - San Fernando.	48° 37′	7 24	12.16
,, - 6 Italian Stations.	64 11	10 58	10.84
,, - Belgrade.	69 55	12 07	10.69
,, - Tiflis.	87 58	14 06	11.55
San Fernando - 6 Italian Stations.	15 34	3 34	8.09
,, - Belgrade.	21 18	4 43	8.36
,, - Tiflis.	39 21	6 42	10.87
6 Italian Stations - Belgrade.	5 44	1 09	9.23
,, - Tiflis.	23 47	3 08	14.05
Belgrade - ,,	18 03	1 59	16.85

From the last table it will be seen that the time of commencement at San Fernando was a little too late, while that at Belgrade was a little too early. Taking together all the results, the mean value of v_1 comes out to be 11.27 km/sec.

* Calcutta and Taungoo are excluded in the calculation of v_1. See §. 89.

94. ***Group 8. Washington, Cheltenham, Toronto, Tiflis; Kodaikanal, Batavia.***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Washington, Cheltenham.	105° 20′	1 08 32	18 44	10.41
Toronto.	101 30	1 06 36	16 48	11.18
Tiflis. (See § 89)	—	—	—	8.47
Kodaikanal. („ § 87)	—	—	—	6.70
Batavia. („ § 88)	—	—	—	9.01

Of the above 5 cases, the results relating to Toronto, Kodaikanal, and Batavia, are probably not quite accurate. (See below.)

v_1 calculated by "Difference Method."

Combination of Stations.			δx	δt_1	v_1
				m s	km/sec.
(i)	Washington, Cheltenham	—Toronto.	3° 50′	1 56	3.67 (?)
(ii)	„	—Tiflis.	77 54	12 44	11.33
(iii)	„	—Kodaikanal.	83 45	12 44	12.18
(iv)	„	—Batavia.	62 45	9 59	11.64
(v)	Toronto	—Tiflis.	74 04	10 48	12.69
(vi)	„	—Kodaikanal.	79 55	10 48	13.70
(vii)	„	—Batavia.	58 55	8 03	13.55
(viii)	Tiflis	—Kodaikanal.	5 51	0 00	(?)
(ix)	Batavia	—Tiflis.	15 09	2 45	10.20
(x)	„	—Kodaikanal.	21 00	2 45	14.14

Of the above 10 combinations, (i) shows that the Toronto time was a little too early. In the three cases of (v), (vi), and (vii), therefore, the volocity deduced would be a little too high.

Again, (viii) shows that the Kodaikanal time was a little too late. Consequently, the value of the velocity in the three cases of (iii), (vi), and (x), would be too high. Excluding these doubtful cases, 7 in number, we find :—

(ii) $v_1=11.33$ km per sec.
(iv) $v_1=11.64$ „
(ix) $v_1=10.20$ „

Of these three cases, the last, relating to Tiflis and Batavia, is probably not so accurate as the other two; the Batavia time being not quite exact, as remarked in § 88. The mean value of the velocity comes out to be **11.49** km per sec.

95. ***Group 9. Honolulu (T.H.) and Irkutsk.***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Irkutsk.	28° 28′	0 55 44	5 56	8.88
Honolulu.	108 27	1 04 36	14 48	13.57

v_1 calculated by "Difference Method."

Honolulu—Irkutsk :—$\delta x=79°59'$; $\delta t_1=8^m\,52^s$. $v_1=16.70$ km/sec.

Judging from the above values of the velocity v_1, the Honolulu time seems to have been a little too early.

96. ***Group 10. Formosa, Bairût (Asia Minor).***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Taihoku.	39° 27′	0 57 19	7 31	9.72
Bairût.	34 41	0 58 00	8 12	7.83

v_1 calculated by "Difference Method."

Bairût—Taihoku..... $\delta x = 4°46'$; $\delta t_1 = -41$ sec.; $v_1 = (?)$km/sec.

The time of commencement at Bairût was evidently a little too late.

97. ***Single Stations.*** "Direct Method."

Station.	Epicentral Distance.		$t_1 - t_0$		v_1
			m	s	km/sec.
Mauritius.	55°	15′	9	06	11.24
Cape Town.	85	46	12	42	12.51
Baltimore.	104	47	20	42	9.37

SUMMARY.

98. ***Velocity and Nature of Path.*** According to the velocity calculations by "difference method" given above, the time (t_1) of earthquake occurrence at some of the stations seem to have been slightly inaccurate, as follows:—

(*a*) t_1 registered at Kodaikanal, Batavia, San Fernando, Baltimore and Bairût was too late; (*b*) t_1 registered at Calcutta, Ponta Delgada, Belgrade, Strassburg, Toronto, and Honolulu, was too early. Some of these stations, whose time observation leads to the values of the transit velocity much different from those for the others, have been excluded in the deduction of the average group velocity.

v_1 *calculated by "direct method."* Comparing together the results for the different groups of stations, we see that there was apparently no general *marked* dependence of v_1 on the nature of the path of the seismic waves; the most trustworthy values of the mean velocity being as follows:—

Group.	Stations.	Nature of Wave Path.	Mean x.	Mean v_1
				km/sec.
1	Tacubaya, Toronto, Victoria, B.C.	Through North Pole.	114° 12′	10.97
2	N. Germany, Great Britain.	Across plane regions.	54 45	10.36
3	S. Austro-Hungary and N. Italy.	Along mountain ranges.	50 44	10.44
,,	New Zealand.		115 24	10.63
5	Jurjew, Upsala.		45 15	10.09
6	Japan.	Through Tibet and China.	49 52	10.13
7	Central and S. Italy.		51 13	10.45
8	Washington, Cheltenham.		105 20	10.41

The stations of Group 1 and New Zealand give high velocities of 10.97 to 10.63 km per sec., the epicentral distances being great and equal to about 115°. It is, however, remarkable that the velocities for Group 2 (mean $x=54°\ 45'$) and Group 3 (mean $x=50°\ 44'$) were practically identical, namely, 10.36 and 10.44 km per sec., although the nature of the regions, through which the seismic waves were propagated, differed widely in the two cases, being respectively across plane grounds and along mountain ranges. The path of the waves for Group 1 stations, which approximately passed through the North Pole, is laid for the greater part across flat grounds.

The 4 Japanese stations of Tokyo, Mizusawa, Osaka, and Kobe (Group 6) give a velocity of 10.13 km per sec., which is about 0.27 km less than those of Group 2 and Group 3 stations. This difference *may* be due to the fact that the seismic waves passed, before reaching Japan, through China and the plateau of Tibet; a natural supposition in this connection being that the propagation velocity would be greater in suboceanic or depressed regions, than in plateau or elevated grounds, on account of the difference of rigidity and elasticity of the material

composing the different portions of the earth's surface.

Taking the average from the different groups of stations given in the preceding table, we find :—

for $x=45°$ to $115°$; . . . . $v_1=$**10.44** km per sec.

99. ***v_1 calculated by "Difference Method."***

The following table gives the mean values of the transit velocity v_1 for the different groups of stations.

Group.	Stations.	Limits of x.	Mean v_1
			km/sec.
1	Tacubaya, Toronto, Victoria, B.C., Colaba.	13° 28′ — 128° 47′	11.63
2	Great Britain, North Germany.	50 36 — 58 54	10.34
3	S. Austro-Hungary, N. Italy, Calcutta, Christchurch, Wellington, Taschkent, Tiflis.	13 42 — 115 24	11.81
5	Porto Rico, Upsala, Jurjew, Batavia, Taschkent	11 20 — 118 25	11.23
6	Japan:—Tokyo, Mizusawa, Osaka, Kobe, Taihoku.	39 27 — 51 33	11.93
7	Tiflis, Belgrade, 6 Italian Stations, San Fernando, New Zealand.	27 26 — 115 24	11.27
8	Washington, Cheltenham, Tiflis, Batavia.	27 26 — 105 20	11.49

Taking the average from the seven groups of stations contained in the above table, with the exception of the 2nd, in which the distance difference was too small, we obtain :—

for $x=11°\ 20'$ to $128°\ 47'$; mean $v_1=$**11.56** km per sec.

100. ***Velocity v_1 calculated by "Direct Method," without reference to the Paths of the Seismic Waves.*** In the following table, the different stations are arranged simply according to the epicentral distance and conveniently divided into a number of groups, the velocity v_1 having been calculated by "direct method." Those stations marked with *asterisks* have not been taken in the deduction of the mean values of the velocity,*

* See page 148.

TABLE IX. v_1 calculated by "Direct Method."

Station.	Epicentral Distance $= x$.	Time of occurrence of 1st Prel. Tremor $= t_1$	v_1
		h m s	km/sec.
Earthquake Origin.	—	**0 49 48**	—
Dehra Dun.	1° 45′	0 50 38	—
Taschkent.	11 20	0 52 24	8.07
Colaba.	13 28	0 53 08	7.48
Calcutta.*	13 42	0 52 00	11.53
Mean.	**12 24**	**0 52 46**	**7.78**
Kodaikanal *	21 35	0 55 48	6.66
5 Caucasus Stations.‡	27 11	0 55 39	8.60
Tiflis.	27 26	0 55 48	8.47
Irkutsk.	28 28	0 55 44	8.88
Mean.	**27 57**	**0 55 46**	**8.68**
Nikolajew.*	37 20	0 58 54	7.60
Taihoku.	39 27	0 57 19	9.72
Bairût.*	34 41	0 58 00	7.83
Batavia.*	42 35	0 58 33	9.01
Jurjew.	42 49	0 57 52	9.87
Manila.	43 34	0 58 25	9.36
Belgrade.	45 29	0 57 47	10.55
Krakau.	45 30	0 58 12	10.03
Mean.	**43 22**	**0 57 55**	**9.91**
Tadotsu.	47 02	0 58 49	9.66
Upsala.	47 41	0 58 22	10.31
Kobe.	48 03	0 58 26	10.30
Osaka.	48 19	0 58 51	9.89

* Not taken in deducing the means.

‡ Achalkalaki, Derbent, Schemacha, Borshom, Batum.

Station.	Epicentral Distance $=x$.	Time of occurrence of 1st Prel. Tremor $=t_1$	v_1
		h m s	km/sec.
Laibach.	48° 19′	0 58 46	9.98
Messina.	49 46	0 59 00	10.02
Potsdam.	49 48	0 58 46	10.28
Triest.	49 52	5 58 44	10.34
Pola.	49 55	5 58 50	10.23
Leipzig.	50 16	0 58 44	10.42
Ischia.	50 30	0 58 56	10.24
Jena.	50 48	0 58 54	10.20
Rocca di papa.	51 15	0 58 51	10.49
Padua.	51 20	0 58 58	10.34
Tokyo.	51 26	0 59 08	10.20
Hamburg.	51 34	0 58 14	11.32
Mizusawa.	51 39	0 59 08	10.25
Göttingen.	51 45	0 58 55	10.51
Querce.	51 54	0 59 08	10.30
Ximeniano.	51 55	0 58 33	10.99
Quarto-Castello.	51 56	0 58 49	10.67
Strassburg.	53 31	0 58 26	11.48
Mean.	**50 24**	**0 58 48**	**10.38**
Kew.	58 05	1 00 12	10.33
Edinburgh.	58 48	1 00 00	10.67
Birmingham.	58 49	1 00 35	10.10
Shide.	58 52	1 01 00	9.73
Liverpool.	59 18	1 00 36	10.17
Paisley.	59 30	1 00 00	10.80
Mean.	**58 54**	**1 00 24**	**10.30**
San Fernando.	66 47	1 02 30	9.74

Station.	Epicentral Distance $=x$	Time of occurrence of 1st Prel. Tremor $=t_1$	v_1
		h m s	km/sec.
Ponta Delgada.*	79° 54′	1 01 00	13.21
Cape Town.	85 46	1 02 30	12.51
Mean.	**73 07**	**1 02 30**	**10.66**
Victoria, B.C.	97 42	1 06 48	10.69
Toronto.	101 30	1 06 36	11.19
Baltimore.*	104 47	1 10 30	9.37
Washington, D.C.	105 17	1 08 25	10.47
Cheltenham.	105 22	1 08 39	10.35
Honolulu.*	108 27	1 04 36	13.57
Mean.	**103 03**	**1 07 49**	**10.61**
Christchurch.	115 03	1 10 00	10.54
Wellington.	115 45	1 09 48	10.72
Porto Rico.	118 25	1 10 25	10.64
Tacubaya.	128 39	1 11 25	10.03
Mean.	**121 16**	**1 10 37**	**10.79**

The mean values of the velocity v_1 contained in the above table are as follows.

TABLE X. Mean Values of v_1 calculated by "Direct Method."

Station.	Epicentral Distance $=x$.	v_1
		km/sec.
Taschkent, Colaba.....	12° 24′	7.78
Tiflis, Irkutsk.	27 57	8.68
Taihoku, Jurjew, Manila, Belgrade, Krakau.	43 22	9.91
Upsala. Osaka, Kobe, Laibach, Triest, Pola, Messina, Ischia, Jena, Tokyo,		

Stations.	Epicentral Distance $=x$.	v_1
		km/sec.
Hamburg, Mizusawa, Rocca di papa, Padova, Querce, Ximeniano, Quarto-Castello, Leipzig, Potsdam, Göttingen, Strassburg.	50° 24′	10.38
Kew, Birmingham, Liverpool, Paisley, Edinburgh, Shide	58 54	10.30
San Fernando and Cape Town.	73 07	10.66
Toronto, Victoria, B. C., Washington, Cheltenham.	103 03	10.61
Christchurch, Wellington, Porto Rico, Tacubaya.	121 16	10.79

As is graphically shown in Fig. 9, the velocity v_1 calculated by "direct method" increased, between the earthquake origin and the epicentral distance of x=about 50°, linearly up to a value of 10.38 km per sec., the velocity at the immediate vicinity of the epicentre being probably some 7 km per sec. For the x greater than 50°, the velocity remained very nearly constant, the maximum being 10.79 km per sec., for $x=121°16'$. According to the above table, the mean velocity (v_1) is as follows :—

$v_1=$**10.52** km per sec. (for $x=50°$ to 121°; mean $x=76.°$)

For the sake of comparison, I give in Fig. 9, also the relation between the epicentral distance and the velocity v_1 calculated by "direct method" for the San Francisco earthquake of April 18, 1906.

101. ***Mean Value of the Velocity v_1 calculated by "Diffence Method."*** The relation between the mean group values of the epicentral distance and the time of occurrence, given in Table IX, is graphically shown in Fig. 7, from which it will be seen

Fig. 7. Indian Earthquake of April 4, 1905. Relation of the Time of Earthquake Occurrence to the Epicentral Distance.

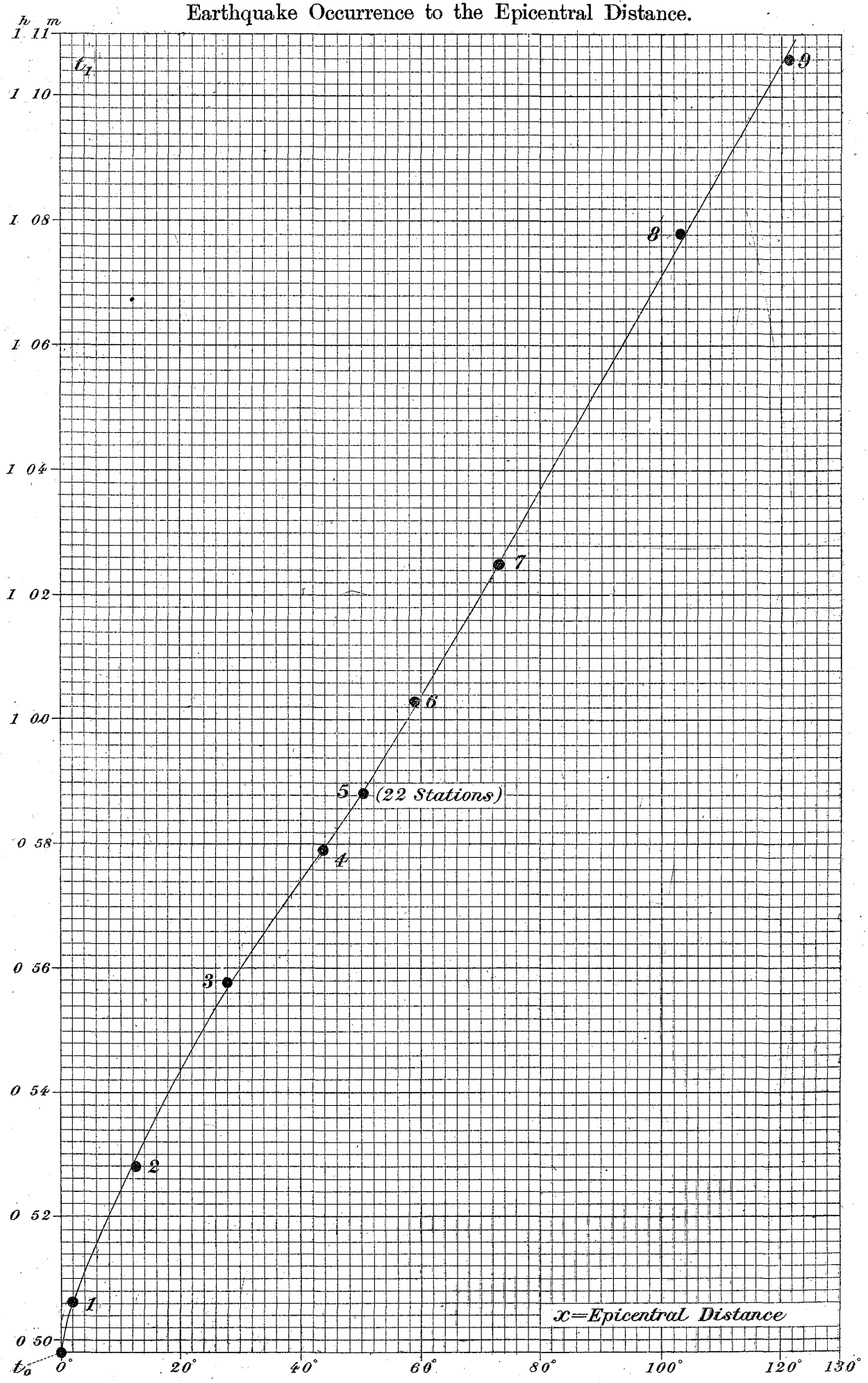
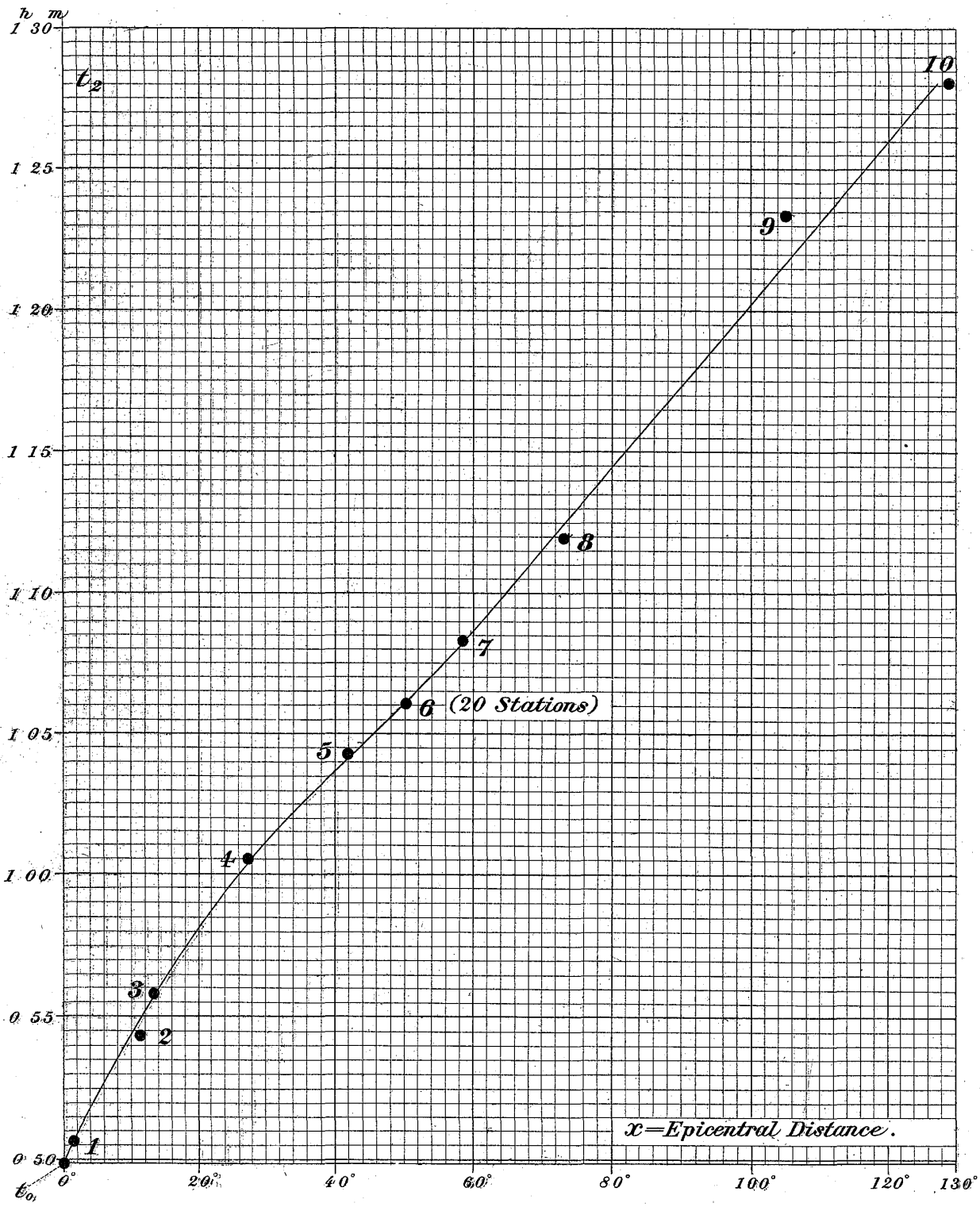


Fig. 8. Indian Eqke of 1905. Relation to the Epicentral Distance of the Time of Occurrence of the 2nd Preliminary Tremor.



Indian Eqke of 1905. Relation to the Epicentral Distance of the Velocities of the 1st and 2nd Preliminary Tremors, Calculated by "Direct Method."

Fig. 9.

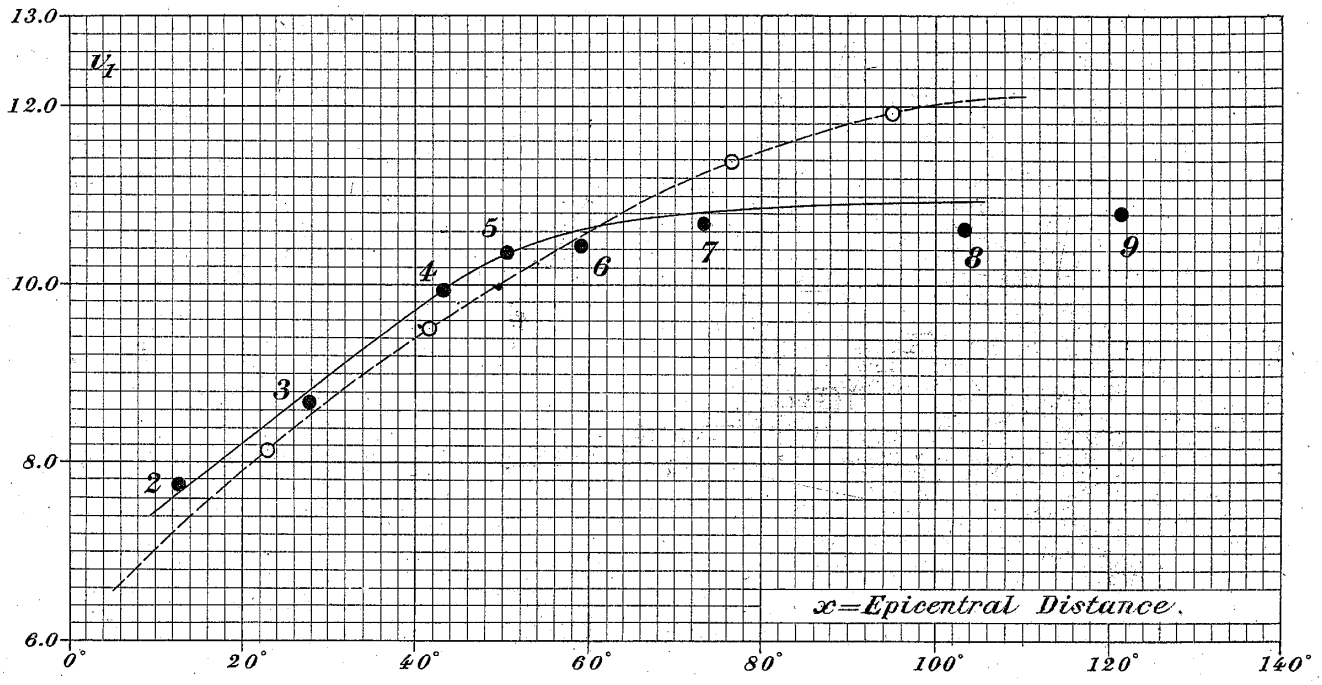
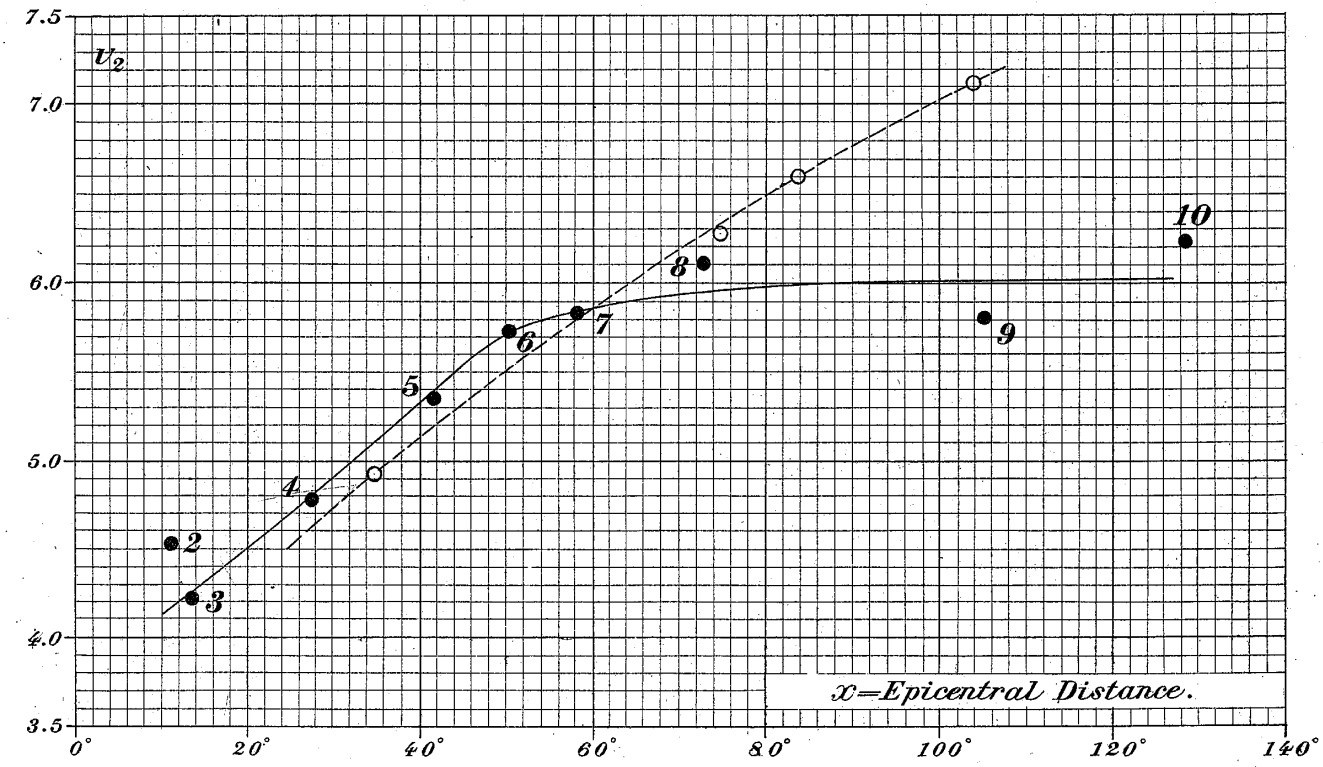


Fig. 10.



Black dots (•) and full line relate to Kangra Eqke.

Small white circle (○) and dotted line relate to San Francisco Eqke.

that the time (t_1) increased almost linearly with the distance (x) between about 30° and 120° (maximum limit).

Taking from Table IX, the mean group values of the epicentral distance and the corresponding time of occurrence of the 1st preliminary tremor, and calculating by the method of Least Squares, we find for the limits of x between 27° 57′ and 121° 16′,

$$v_1 = \mathbf{11.36} \text{ km per sec.}$$

Chapter V. Velocity of Propagation of the 2nd Preliminary Tremor.

102. ***Time of Commencement*** (t_2) ***and Transit Velocity*** (v_2) ***at Different Stations.*** The following table gives the epicentral distance (x) and the time of commencement (t_2) of the 2nd preliminary tremor for the 42 stations, whose seismograms indicated the last mentioned phase of motion with clearness; the different stations being divided, according to the epicentral distance, into a number of groups. The velocity v_2 given in the 4th column of the table has been calculated by "direct method" according to the formula

$$v_2 = \frac{x}{t_2 - t_0};$$

t_0 being the time of earthquake occurrence at the origin, assumed to be $0^h\ 49^m\ 48^s$ (G.M.T.).

Again, as will be seen from the results of the calculation of the velocity v_2 by "difference method" the times t_2 for Kodaikanal, Taungoo, and Batavia, seem to be a little too late. Accordingly these 3 stations (marked with *asterisks* in the Table) have been