Preliminary Note on the Seismographic Observations of the San Francisco Earthquake of April 18, 1906.*

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. In response to my circular asking for a copy of the seismographic or magnetographic records of the San Francisco earthquake of April 18, 1906, photographic or printed reproductions of the diagrams have been sent in from the following 35 stations :— *Lick Observatory ; Washington, D.C.; Cheltenham ; Tacubaya* (Mexico); *Victoria, B.C.; Toronto ; Honolulu ; Mizusawa ; Osaka ; Kobe ; Tadotsu ; Taihoku* (Formosa); *Paisley; Edinburgh ; Kew ; Shide* (Isle of Wight); *Strassburg ; Pola ; Quarto Castello, Querce and Ximeniano* (Florence); *Casamicciola and Porto d'Ischia,* in the Island of Ischia; *San Fernando; Tashkent ; Cairo ; Kodaikanal* (Madras) ; *Calcutta ; Dehra Dun; Batavia; Manila ; Zikawei* (Shanghai); *Wellington* and *Christchurch* (New Zealand); *Rio de Janeiro.* I take this opportunity of expressing my thanks to the seismologists in charge of these observatories for having so kindly supplied me with the results of their observations.

Table 1 gives a list of the latitude, longitude, epicentral distance, and the time of occurrence of the 1st preliminary tremor for Tokyo, and for each of the 35 above-mentioned stations, as well as 31 other places, namely :—*Berkeley; Ukiah* (California); *Baltimore; Baldwin* (Kansas); *Ottawa ; Vieques* (Porto *Rico); Sitka* (Alaska); *Bergen* (Norway); *Hamburg; Göttingen; Heidelberg; Jena;*

* A note on the Tokyo observation of the San Francisco earthquake, with one of the seismograms, has been given in the *Publications of the Earthq. Inv. Comm.*, No. 21, App. II.

Krakau; Kremsmuenster; Vienna; Laibach; Budapest; O'Gyalla; Triest; Fiume; Zagreb (Croatia); *Sarajevo* (Bosnia); *Agram; Tortosa; Ebro; Cartuja* (Granada); *Belgrad; Sofia; Jurjew; Tiflis; Fremantle* (Australia). The times of commencement of the 1st and 2nd preliminary tremors relating to these latter places have been taken from Dr. Bauer's paper, entitled "Seismograph and magnetograph records of the San Francisco earthquake,"* and from the monthly or weekly reports of the different seismological observatories.

The velocities of propagation corresponding to the commencements of the 1st and 2nd preliminary tremors are denoted by v_1 and v_2; the calculation being made both according to the "direct method" and the "difference method", as explained in one of the preceding Articles. t_1 and t_2 denote respectively the times of commencement of the 1st and 2nd preliminary tremors at a given station, whose epicentral distance is x. t_0 denotes the time of earthquake occurrence at the origin.

In the calculation of the epicentral distance of a station, the position of the seismic origin has been fixed according to the preceding Article, at a point, *latitude* 38° 15′ N, *longitude* 123° W; the time of commencement of the earthquake motion at the origin being assumed to be $13^h\ 12^m\ 00^s$ G.M.T.

* The *Popular Science Monthly*, August, 1906.

TABLE I.--OBSERVATION OF THE SAN FRANCISCO EARTHQUAKE OF APRIL 18, 1906.

(*.....Time determined from magnetograms.)

Place.	Position.		Epicentral Distance. $=x$	Time of occurrence (G.M.T.)
	Latitude.	Longitude.		
Origin	38° 15′ — N	125° — W	———	$13^h12^m00^s$
United States.				
University, Berkeley	37° 52′ 24″ N	122°15′11″ W	0° 42′	13 12 39
Lick Observatory.....	37° 20′ 25″ N	121°38′44″ W	1 24	13 12 12
Ukiah.	39° 08′ 12″ N	125°13′— W	0 54	13 12 17
Washington, D.C.....	38° 54′ 18″ N	77°03′06″ W	35 32	13 19 20
Cheltenham	38° 44′ — N	76°50′30″ W	35 44	13 19 24 13 30 00*
Baltimore	39° 17′ 48″ N	76°37′12″ W	35 46	13 19 24
Baldwin.....	38° 47′ — N	95°10′— W	21 42	13 24 —*
Mexico.				
Tacubaya	19° 24′ 18″ N	99°11′37″ W	27° 57′	13 17 58
Canada.				
Victoria, B.C.	48° 27′ — N	123°22′— W	10° 12′	13 14 12
Toronto.....	43° 39′ 36″ N	79°23′24″ W	32 59	13 19 18
Ottawa	45° 26′ — N	75°40′— W	35 27	13 17 59
Porto Rico.				
Vieques.....	18° 09′ — N	65°26′— W	53° 38′	13 22 17
Alaska.				
Sitka.....	57° 03′ — N	135°20′— W	20° 29′	13 17 01 13 22 54*
Hawaii.				
Honolulu	21° 19′ — N	153°04′— W	30° 53′	13 19 30 13 27 48*
Japan.				
Mizusawa.....	39° 08′ — N	141°07′— E	70° 50′	13 24 07
Tokyo	35° 42′ 29″ N	139°45′53″ E	73 41′	13 24 35
Osaka	34° 42′ — N	135°31′— E	77 04	13 24 24

TABLE I.—*Continued.*

Place.	Position.		Epicentral Distance $=x$.	Time of occurrence (G.M.T.)
	Latitude.	Longitude.		
				h m s
Kobe	34° 41′ — N	135°11′— E	77° 17′	13 24 23
Tadotsu	34° 17′ — N	133°46′— E	78 27	13 25 07
Taihoku(Formosa)	25° 02′ — N	121°30′— E	92 33	13 27 20
Great Britain.				
Paisley	55° 51′ — N	4°25′— W	72° 27′	13 23 12
Edinburgh	55° 57′ 23″ N	3°10′46″W	72 53	13 23 30
Kew	51° 28′ 06″ N	0°18′46″W	77 17	13 25 42
Shide (New Port)	50° 42′ — N	1°19′— W	77 25	13 25 00
Birmingham	52° 28′ — N	1°53′— W	75 54	13 25 03
Norway.				
Bergen	60° 30′ — N	5°25′— E	72° 38′	13 22 46
Germany.				
Hamburg	53° 33′ 55″ N	10°01′19″ E	79° 38′	13 24 32
Göttingen	51° 33′ — N	9°58′— E	81 15′	13 24 34
Heidelberg	49° 23′ 55″ N	5°58′44″ E	81 28	13 25 23
Jena	50° 56′ — N	11°35′— E	82 21	13 24 34
Strassburg	48° 35′ 00″ N	7°46′10″ E	82 49	13 24 56
Austria-Hungary.				
Krakau	50° 03′ 50″ N	19°57′36″ E	85° 51′	13 35 48
Kremsmünster	48° 03′ — N	14°08′— E	85 40	13 24 25
Vienna	48° 13′ 55″ N	16°20′23″ E	86 17	13 25 42
Laibach	46° 03′ — N	14°31′— E	87 29	13 25 25
Budapest	47° 22′ 29″ N	19°03′55″ E	87 56	13
O'Gyalla	47° 52′ 24″ N	18°52′32″ E	87 26	13 25 20
Pola	44° 51′ 49″ N	13°50′44″ E	88 15	13 25 56
Triest	45° 38′ 45″ N	13°45′45″ E	87 33	13 24 33
Fiume	45° 19′ 56″ N	14°25′40″ E	88 05	13 40 00
Zagreb	45° 48′ 54″ N	15°58′48″ E	88 13	13 25 25
Sarajevo	43° 52′ — N	18°44′— E	90 53	(?)
Agram	45° 50′ — N	16°08′— E	88 16	13 25 17
Italy.				
Quarto Castello	43° 49′ 11″ N	11°13′11″ E	88 ′05	13 27 15
Querce	43° 47′ 18″ N	11°16′42″ E	88 08	13 25 00
Ximeniano	43° 46′ 40″ N	11°15′24″ E	88 08	13 26 25
Porto d'Ischia	40° 44′ 27″ N	13°56′34″ E	91 46	13 26 59

TABLE I.—*Continued.*

Place.	Position.		Epicentral Distance $=x$.	Time of occurrence (G.M.T.)
	Latitude.	Longitude.		h m s
Casamicciola	40° 44′ 45″ N	13°54′12″ E	91° 44′	13 26 08
Spain.				
San Fernando.	36° 27′ 40″ N	6°12′19″ W	85° 14′	13 25 06
Tortosa	40° 49′ — N	2°34′ — E	86 37	13 24 55
Cartuja (Granada)	37° 10° 45″ N	0°05′25″ E	88 08	13 24 40
Ebro	40° 49′ 12″ N	0°29′40″ E	85 36	13 24 55
Servia.				
Belgrad	44° 48′ — N	20°09′ — E	90° 33′	13 36 54
Bulgaria.				
Sofia	42° 42′ — N	23°20′ — E	93° 28′	13 25 00
Russia.				
Jurjew	58° 25′ — N	26°42′ — E	80° 05′	13 24 39
Tiflis	41° 43′ 08″ N	44°47′51″ E	99 16	13 27 17
Taschkent	41° 19′ 31″ N	69°17′42″ E	99 38	13 28 05
Egypt.				
Cairo	30° 04′ 33″ N	31°17′14″ E	107° 35′	13 31
India.				
Kodaikanal	10° 13′ 50″ N	77°27′46″ E	127° 53′	13 31 36
Calcutta	22° 34′ — N	88°24′ — E	112 25	13 19 54
Batavia	6° 08′ — S	106°50′ — E	117 18	13 32 54
Manila	14° 34′ 41″ N	120°58′33″ E	100 14	13 22 42
Shanghai	31° 11′ 33″ N	121°10′45″ E	88 24	13 34 59
New Zealand.				
Wellington	41° 17′ — S	174°47′ — E	97° 40′	13 26 36
Christchurch	43° 31′ 50″ S	172°37′18″ E	100° 23′	13 33 36
Brazil.				
Rio de Janeiro	22° 54′ 24″ S	43°10′21″ W	96° 30′	13 59 41(?)
Australia.				
Fremantle	32° 03′ — S	115°44′ — E	90° 58′	13 46 50

Table II gives the times of occurrence of the 1st preliminary tremor at the different stations, divided into a number of groups, according to the epicentral distance ; those places, whose time observations are apparently not quite exact, being *provisionally* excluded.

TAELE II.—SAN FRANCISCO EARTHQUAKE OF APRIL 18, 1906.

Different Stations divided into Groups.

Place.	Epicentral Distance $=x$.	Time of occurrence. $=t_1$(G. M. T.)
		h m s
Origin.	———	**13 12 00**
Victoria, B.C.....	10° 12′	13 14 12
Sitka	20° 29′	13 17 01
Tacubaya	27° 57′	13 17 58
Honolulu.....	30° 53′	13 19 30
Toronto	32° 59′	13 19 18
Mean	**30° 36′**	**13 18 55**
Ottawa.....	35° 27′	13 17 59
Washington	35° 32′	13 19 20
Cheltenham	35° 44′	13 19 24
Baltimore	35° 46′	13 19 24
Mean.....	**35° 37′**	**13 19 02**
Vieques	53° 38′	13 22 17
Mizusawa	70° 50′	13 24 07
Tokyo	73° 41′	13 24 35
Osaka	77° 04′	13 24 24
Kobe	77° 17′	13 24 23
Mean	**74° 43′**	**13 24 22**
Bergen	72° 38′	13 22 46

TABLE II.—*Continued.*

Place.	Epicentral Distance $=x$	Time of occurrence. $=t_1$ (G. M. T.)
		h m s
Paisley	72° 27′	13 23 12
Edinburgh	72 53	13 23 30
Birmingham	75 54	13 25 03
Kew	77 17	13 25 42
Shide	77 25	13 25 00
Hamburg	79 38	13 24 32
Jurjew	80 05	13 24 39
Göttingen	81 15	13 24 34
Heidelberg	81 28	13 25 23
Jena	82 21	13 24 34
Strassburg	82 49	13 24 56
Mean	**78 01**	**13 24 29**
San Fernando	85° 14′	13 25 06
Ebro	85 36	13 24 55
Kremsmünster	85 40	13 24 25
Vienna	86 17	13 25 42
Tortosa	86 37	13 24 55
O'Gyalla	87 26	13 25 20
Laibach	87 29	13 25 25
Triest	87 33	13 24 33
Quarto Castello	88 05	13 27 15
Querce	88 08	13 25 00
Ximeniano	88 08	13 26 25
Cartuja (Granada)	88 08	13 24 40
Zagreb	88 13	13 25 25
Pola	88 15	13 25 56
Agram	88 16	13 25 17
Ischia*	91 45	13 26 34
Taihoku	92 23	13 27 20
Sofia	93 28	13 25 00
Mean	**88 09**	**13 25 31**
Wellington	97° 40′	13 26 36
Tiflis	99 16	13 27 17
Taschkent	99 38	13 28 05
Batavia	117 18	13 32 54
Kodaikanal	127 53	13 31 36
Mean	**108 21**	**13 29 18**

* Mean of Porto d'Ischia and Casamicciola.

2. *Velocity of Propagation of the 1st Preliminary Tremor.*

"DIRECT METHOD."

(i)* Victoria, B.C.

$x = 10°12' = 1133$ *km.*

$t_1 = 1^h14^m12^s$

$t_1 - t_0 = 2^m12^s = 132$ sec.

$v_1 = 8.58$ *km* per sec.

(ii)* Sitka.

$x = 20°\ 29' = 2276$ *km.*

$t_1 = 1^h17^m01^s$

$t_1 - t_0 = 5^m01^s = 301$ sec.

$v_1 = 7.56$ *km* per sec.

(iii) Tacubaya, Honolulu, Toronto :—

Mean.....$x = 30°\ 36' = 3400$ *km.*

$t_1 = 1^h18^m55^s$

$t_1 - t_0 = 6^m55^s = 415$ sec.

$v_1 = 8.19$ *km* per sec.

(iv) Eastern Parts of Canada and the United States:—*Ottawa, Washington, D.C., Cheltenham, Baltimore.*

Mean.....$x = 35°\ 37' = 3956$ *km.*

$t_1 = 1^h19^m02^s$

$t_1 - t_0 = 7^m02^s = 422$ sec.

$v_1 = 9.37$ *km* per sec.

(v)* Vieques (Porto Rico).

$x = 53°\ 38' = 5958$ *km.*

$t_1 = 1^h22^m17^s$

$t_1 - t_0 = 10^m17^s = 617$ sec.

$v_1 = 9.66$ *km* per sec.

(vi) Japan:—*Mizusawa, Tokyo, Osaka, Kobe.*

Mean.....$x = 74°\ 43' = 8301$ *km.*

$t_1 = 1^h24^m22^s$

$t_1-t_0=12^m22^s=742$ sec.
$v_1=11.19$ *km* per sec.

(vii) Norway, Great Britain, Germany, Russia:—*Bergen, Paisley, Edinburgh, Birmingham, Kew, Shide, Hamburg, Göttingen, Heidelberg, Jena, Strassburg, Jurjew.*

Mean.....$x=78°\ 01'=8667$ *km.*
$t_1=1^h24^m29^s$
$t_1-t_0=12^m29^s=749$ sec.
$v_1=11.57$ *km* per sec.

(viii) Spain, Austro-Hungary, Italy, Burgaria, Formosa:—*San Fernando, Tortosa, Kremsmuenster, Vienna, O'Gyalla, Laibach, Triest, Quarto Castello, Querce, Ximeniano, Cartuja, Zagreb, Pola, Agram, Ischia, Taihoku, Sofia.*

Mean.....$x=88°\ 09'=9793$ *km.*
$t_1=1^h25^m31^s$
$t_1-t_0=13^m31^s=811$ sec.
$v_1=12.08$ *km* per sec.

(ix) New Zealand, Turkestan, Java, India:—*Wellington, Christchurch, Tiflis, Taschkent, Batavia, Kodaikanal.*

Mean.....$x=108°\ 21'=12038$ *km.*
$t_1=1^h29^m18^s$
$t_1-t_0=17^m18^s=1038$ sec.
$v_1=11.60$ *km* per sec.

Excluding provisionally the three cases of single observations, (i), (ii), and (v) marked with *asterisks*, the six groups (iii). (iv), (vi)—(ix), may be divided into two sets as follows:—

(**a**).....(iii), (iv) ..... $x=30°\ 36'$; $v_1=8.19$ *km* per sec.
$x=35°\ 37'$; $v_1=9.37$,,
Mean .....$x=33°\ 7'$; $v_1=8.78$,,

(**b**).....(vi), (vii), (viii), (ix).

$x=74°$	$43'$;	$v_1=11.19$ *km* per sec.
78	01	11.57
88	09	12.08
108	21	12.60

Mean..... $x=87°\ 19'$ $v_1=$**11.61** *km* per sec.

Comparing the latter value with the velocity deduced by "difference method" given below, we obtain:—

$$\frac{v_1\text{(difference method)}}{v_1\text{(direct method)}}=\frac{13.97}{11.61}=12.03$$

This ratio is to be regarded as holding good, so far as the velocity calculated hy "direct method" is concerned, for the distance x of about 70° to 100°.

The relation between the x and v_1 calculated by "direct method," for the six groups (iii), (iv), (vi).....(ix), is graphically shown in Fig. 2, Pl. IX.

"DIFFERENCE METHOD."

In calculating the velocity v_1 by the "difference method", I have taken only the mean values relating to the Groups (iii), (iv), (vi).....(ix). The relation between the time of commencement and the epicentral distance is illustrated in Fig. 1, the dotted curve being drawn with free hand through the mean position. Assuming a linear relation between the time of commencement and the epicentral distance for the limits of the latter quantity given by the groups (iii) and (ix), as indicated by the straight line in Fig. 1, and calculating by the method of Least Squares, we obtain

$v_1=$**13.97** *km.* per sec.

3. *Velocity of Propagation of the 2nd Preliminary Tremor.*

Table III gives, for 21 different stations, the epicentral distance and the time ($=t_2$) of commencement of the 2nd preliminary tremor ; the stations being grouped as follows :—

Group (i). United States and Canada:—*Toronto, Cheltenham, Baltimore.*

Group (ii). Japan :—*Mizusawa*, *Tōkyo*, *Osaka*, *Kobe*.

Group (iii). Central Europe:—*Hamburg*, *Jurjew*, *Göttingen*, *Jena*, *Strassburg*, *San Fernando*, *O'Gyalla*, *Quarto Castello* (Florence), *Zagreb*.

The epicentral distance varied between 79° 38′ and 88° 13′.

Group (iv). *Tiflis*, *Manila*, *Calcutta*, the epicentral distance varying between 99° 16′ and 112° 25′.

Besides these, there are two single stations of Birmingham ($x=75°\ 54'$) and Sofia ($x=93°\ 28'$).

The relation between the time (t_2) and the distance x, for the four groups (i)—(iv), is illustrated in Fig. 3, (Pl. X).

TABLE III.—SAN FRANCISCO EARTHQUAKE.

Time of Commencement of the 2nd Preliminary Tremor.

Place.	Epicentral Distance $=x$.	Time of Commt. of 2nd Prel. Tremor. $=t_2$.
		h m s
Toronto	32° 59′	13 25 00
Cheltenham	35 44	13 25 04
Baltimore	35 46	13 25 12
(i) Mean	**34 50**	**13 25 05**
Mizusawa	70° 50′	13 33 14
Tokyo	73 41	13 34 24
Osaka	77 04	13 34 13
Kobe	77 17	13 34 19
(ii) Mean	**74 43**	**13 34 03**
Birmingham	75° 54′	13 35 07
Hamburg	79° 38°	13 34 57
Jurjew	80 05	13 34 43
Göttingen	81 15	13 34 42
Jena	82 21	13 35 09

Place.	Epicentral Distance $=x$.	Time of Commt. of 2nd Prel. Tremor $=t_2$.
		h m s
Strassburg	82° 49′	13 35 20
San Fernando	85 14	13 35 18
O'Gyalla	87 26	13 36 08
Quarto Castello	88 05	13 37 58
Zagreb	88 13	13 35 32
(iii) Mean	**83 54**	**13 35 32**
Tiflis	99° 16′	13 39 13
Manila	100 14	13 37 02
Calcutta	112 25	13 40 48
(iv) Mean	**103 58**	**13 39 01**

Calculating the velocity of propagation from the *mean* values given in the above table we obtain the following results.

"DIRECT METHOD."

(i) $x = 34° 50′ = 3870$ *km.*

$t_2 = 1^h25^m05^s$

$t_2 - t_0 = 13^m05^s = 785$ sec.

$v_2 = 4.93$ *km.* per sec.

(ii) $x = 74° 43′ = 8301$ *km.*

$t_2 = 1^h34^m03^s$

$t_2 - t_0 = 22^m03^s = 1323$ sec.

$v_2 = 6.27$ *km.* per sec.

(iii) $x = 83° 54′ = 9321$ *km.*

$t_2 = 1^h35^m32^s$

$t_2 - t_0 = 23^m32^s = 1412$ sec.

$v_2 = 6.60$ *km.* per sec.

(iv) $x = 103° 58′ = 11551$ *km.*

$t_2 = 1^h39^m01^s$

$t_2 - t_0 = 27^m01^s = 1621$ sec.

$v_2 = 7.13$ *km.* per sec.

The above results may be summarized as follows :—

(A) For (i) in which the epicentral distance was 34° 50′, the *direct* velocity v_2 was 4.93 *km.* per sec.

(B) For (ii) and (iii), in which the distance was 74° 43′ to 83° 54′, the mean values are :

$x = 79°\ 19'$, $v_2 = 6.44$ *km.* per sec.

(C) For (iv), in which the distance was great and equal to 103°58′, the velocity v_2 was 7.13 *km.* per sec.

The relation between the epicentral distance and the velocity v_2, calculated by the "direct method", is graphically shown in Fig. 4, Pl. XI, the curve being, within the limits of 34° 50′ and 103° 58′, approximately straight.

"DIFFERENCE METHOD."

(iv)−(i);.....$\delta x = 69°\ 08' = 7680$ *km.*

$\delta t = 13^m55^s = 835$ sec.

$v_2 = 9.20$ *km.* per sec.

(iv)−(ii);.....$\delta x = 29°\ 15' = 3249$ *km.*

$\delta t = 4^m58^s = 298$ sec.

$v_2 = 10.90$ *km.* per sec.

(iv)−(iii);.....$\delta x = 20°\ 04' = 2227$ *km.*

$\delta t = 3^m29^s = 209$ sec.

$v_2 = 10.66$ *km.* per sec.

(iii)−(i); .....$\delta x = 49°\ 04' = 5450$ *km.*

$\delta t = 10^m27^s = 627$ sec.

$v_2 = 8.69$ *km.* per sec.

(iii)—(ii).....$\delta x = 9^\circ\ 11' = 1010$ *km.*

$\delta t = 1^m 29^s = 89$ sec.

$v_2 = 11.35$ *km.* per sec.

(ii)—(i).....$\delta x = 39^\circ\ 53' = 4430$ *km.*

$\delta t = 8^m 58^s = 538$ sec.

$v_2 = 8.24$ *km.* per sec.

The above results may be summarized as follows :—

(A). For the three combinations, in each of which the shorter distance was 34° 50′, the velocity v_2 was small, namely,

$v_2 = 9.20$ *km.* per sec.
8.69
8.24

Mean.....**8.71** *km.* per sec.

(B). For the three remaining combinations, in each of which the shorter distance was over 74° 43′, the velocity was greater :—

$v_2 = 10.90$ *km.* per sec.
10.66
11.35

Mean.....**10.97** *km.* per sec.

Mean value of v_2. Taking the four groups (i).....(iv), Table III, and assuming a linear equation between the epicentral distance and the time of commencement of the 2nd preliminary tremor, we obtain by method of Least Squares, the following mean value :—

$v_2 = \mathbf{9.02}$ *km.* per sec.

Comparing this with the value of the velocity v_1 given in §2, we see that

$$\frac{v_1}{v_2} = \frac{13.97}{9.02} = 1.549\,;$$

this ratio relating to the velocities between the distance limits of about 30° and 100°

4. *Duration of the 1st Preliminary Tremor.*

Table IV gives the duration (y_1) of the 1st preliminary tremor at the different stations, arranged according to the epicentral distance (x).

TABLE IV.—SAN FRANCISCO EARTHQUAKE.

Duration of the 1st Preliminary Tremor.

Place.	Epicentral Distance=x	Duration of 1st Prel. Tremor=y_1
		m s
Tacubaya	27° 57′	4 53
Ottawa	35° 27′	5 31
Washington	35° 32′	5 26
Cheltenham	35° 44′	5 38
Mean	**35° 34′**	**5 32**
Vieques (Porto Rico)	53° 38′	7 38
Mizusawa	70° 50′	9 07
Tokyo	73° 41′	9 49
Osaka	77° 04′	9 49
Kobe	77° 17′	9 56
Mean	**74° 43′**	**9 40**
Paisley	72° 27′	10 12
Birmingham	75° 54′	10 04
Kew	77° 17′	8 12
Hamburg	75° 54′	10 25
Jurjew	80° 05′	10 04
Göttingen	81° 15′	10 08
Jena	82° 21′	10 35
Strassburg	82° 49′	10 24
Mean	**78° 30′**	**10 01**
Ximeniano	88° 08′	10 57
Querce	88° 08′	10 42
Quarto Castello	88° 05′	10 56

TABLE IV.—*Continued.*

Place.	Epicentral Distance=x.	Duration of 1st Prel. Tremor=y_1.
		m s
Ischia	91° 45′	11 27
Mean	**89° 02′**	**11 01**
Tiflis	99° 16′	11 56
Manila	100° 14′	14 20
Mean	**99° 45′**	**13 08**

According to Table IV the mean values of the epicentral distance (x) and the corresponding duration (y_1) of the 1st preliminary tremor are as follows:—

x=27° 57′ ;	y_1=4^m 53^s
35° 34′	5 32
53° 38′	7 38
74° 43′	9 40
78° 30′	10 01
89° 02	11 01
99° 45′	13 08

The relation of x and y_1, as illustrated in Fig. 5, Pl. XII, is nearly linear. Assuming, therefore, an equation of the 1st degree between these two quantities, and determining the constants by the method of Least Squares, we obtain the following formula:—

$$x = 16.79\, y_1 - 1618 \; km.$$

The deduction of this equation, whose application is limited between x=about 30° and 100°, differ from that of similar equations hitherto given in that the data utilized in the calculation relate all to one and the same earthquake, and not to the observations at one given station of different earthquakes.

5. *Milne Horizontal Pendulum Seismograms obtained at San Fernando and Wellington.*

In Figs 6 and 7, Pl. XIII, I reproduce the Milne Horizontal Pendulum seismograms obtained at San Fernando (Spain) and Wellington (New Zealand); these records having been selected on account of the clearness with which they indicate the W_2 waves, or the earthquake vibrations propagated along the major arcs of the earth. The explanation to the Wellington diagram is that given by Mr. G. Hogben.

In each diagram, the letter *A* marks the probable commencement of the 3rd phase of the principal portion.

The portion marked W_3 in the San Fernando diagram may correspond to the repetition of the earthquake motion propagated first along the minor arc, which came back after making one complete circuit of the earth.*

The epicentral distances of San Fernando and Wellington are respectively 85° 14′ and 97° 40′, the former station being 12° 26′ or 1381 km nearer to the origin of the earthquake. Accordingly the W_2 motion occurred some minutes earlier in the Wellington record than in the San Fernando one.

San Fernando Seismogram. Commencement of the earthquake $=13^h\ 25^m\ 06^s$. The principal portion began approximately at $13^h\ 49^m\ 30^s$. The first maximum motion, probably corresponding to the 3rd phase of the principal portion, occurred at $13^h\ 57^m\ 18^s$; the 2nd maximum occurring at $14^h\ 03^m\ 05^s$.

The W_2 motion began at $15^h\ 13^m$, the 3rd phase of its principal portion commencing at $15^h\ 32^m\ 42^s$. The motion remained active till $15^h\ 46^m$.

Wellington Seismogram. Commencement of the earthquake

* Mr. Hogben identifies the earthquake movements for the successive repetitions.

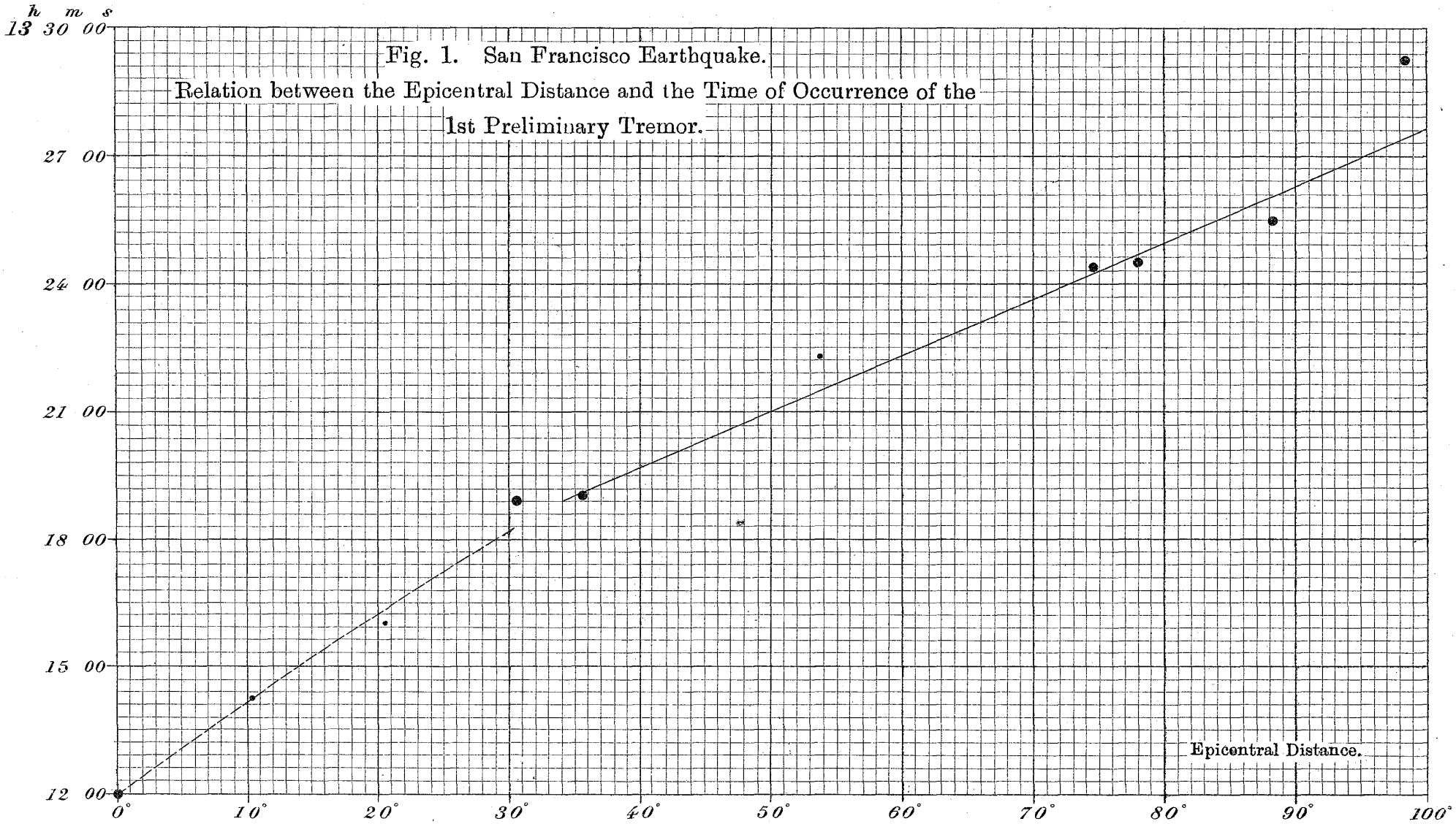


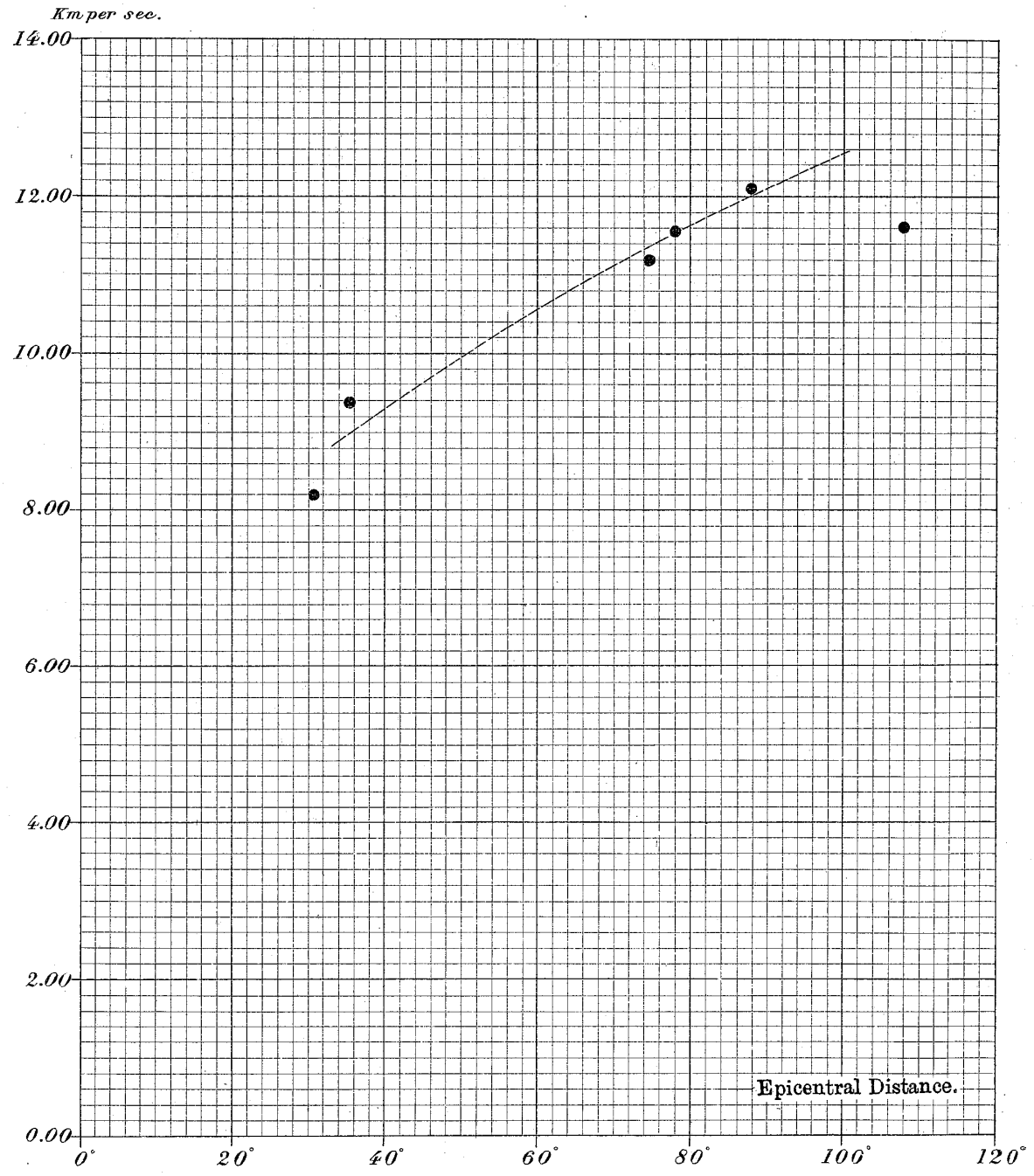
Fig. 1. San Francisco Earthquake.

Relation between the Epicentral Distance and the Time of Occurrence of the 1st Preliminary Tremor.

A large dot relates to a mean group value, while a small dot relates to a single value.

Fig. 2. San Francisco Earthquake.

Relation between the Epicentral Distance and the Velocity v_1, "directly" calculated.



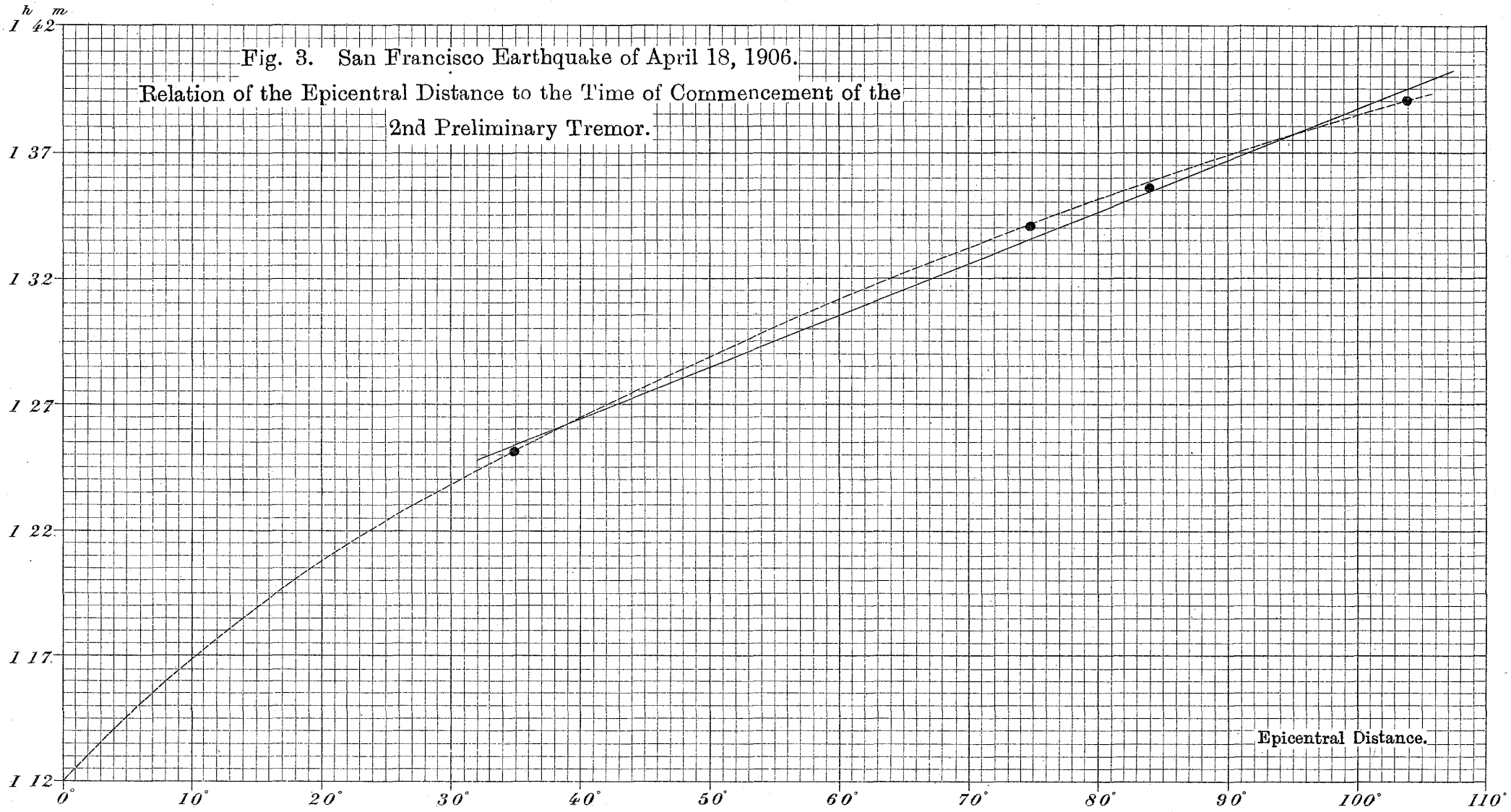
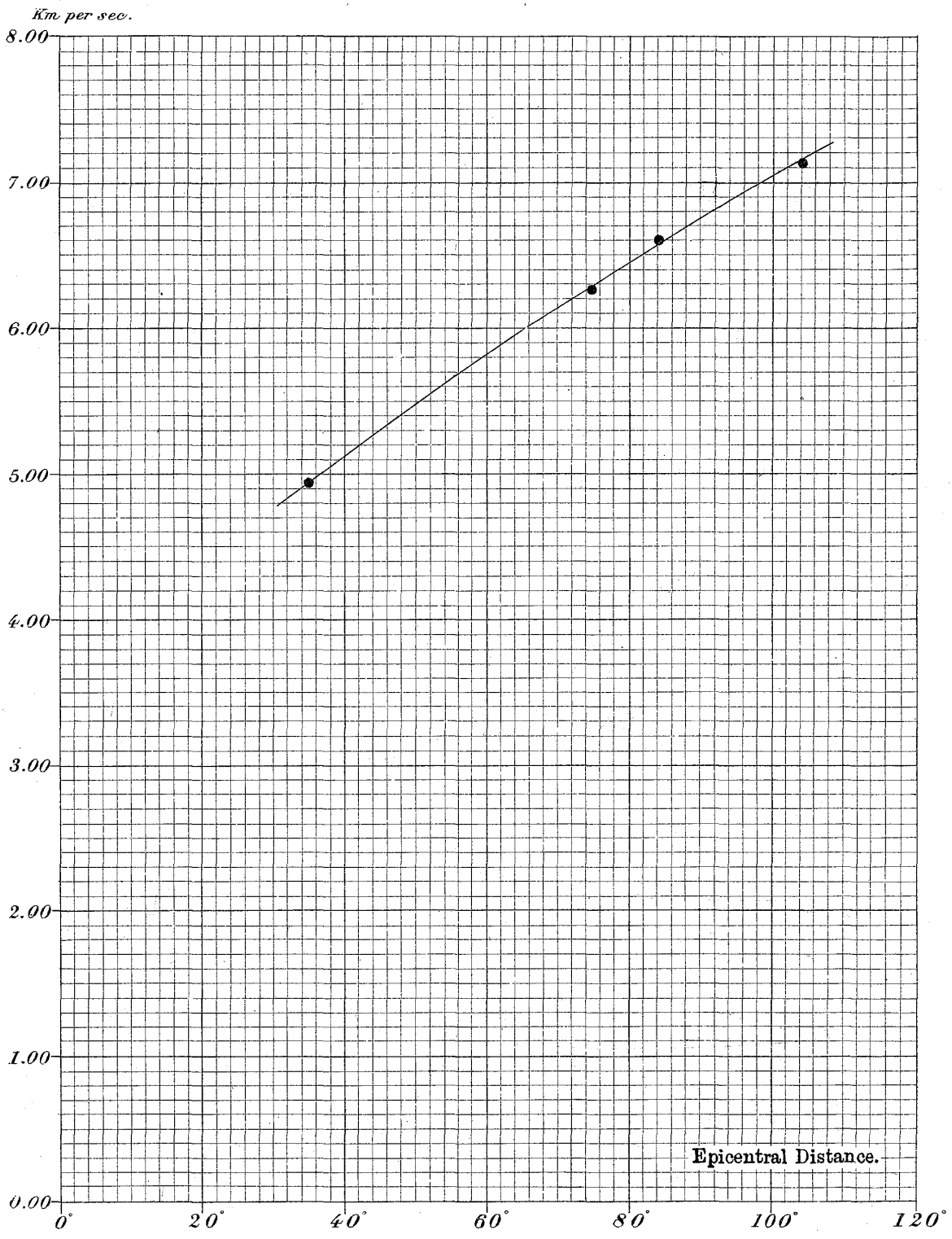


Fig. 3. San Francisco Earthquake of April 18, 1906.
Relation of the Epicentral Distance to the Time of Commencement of the 2nd Preliminary Tremor.

Fig. 4. San Francisco Earthquake.

Relation between the Epicentral Distance and the Velocity v_2, " directly " calculated.



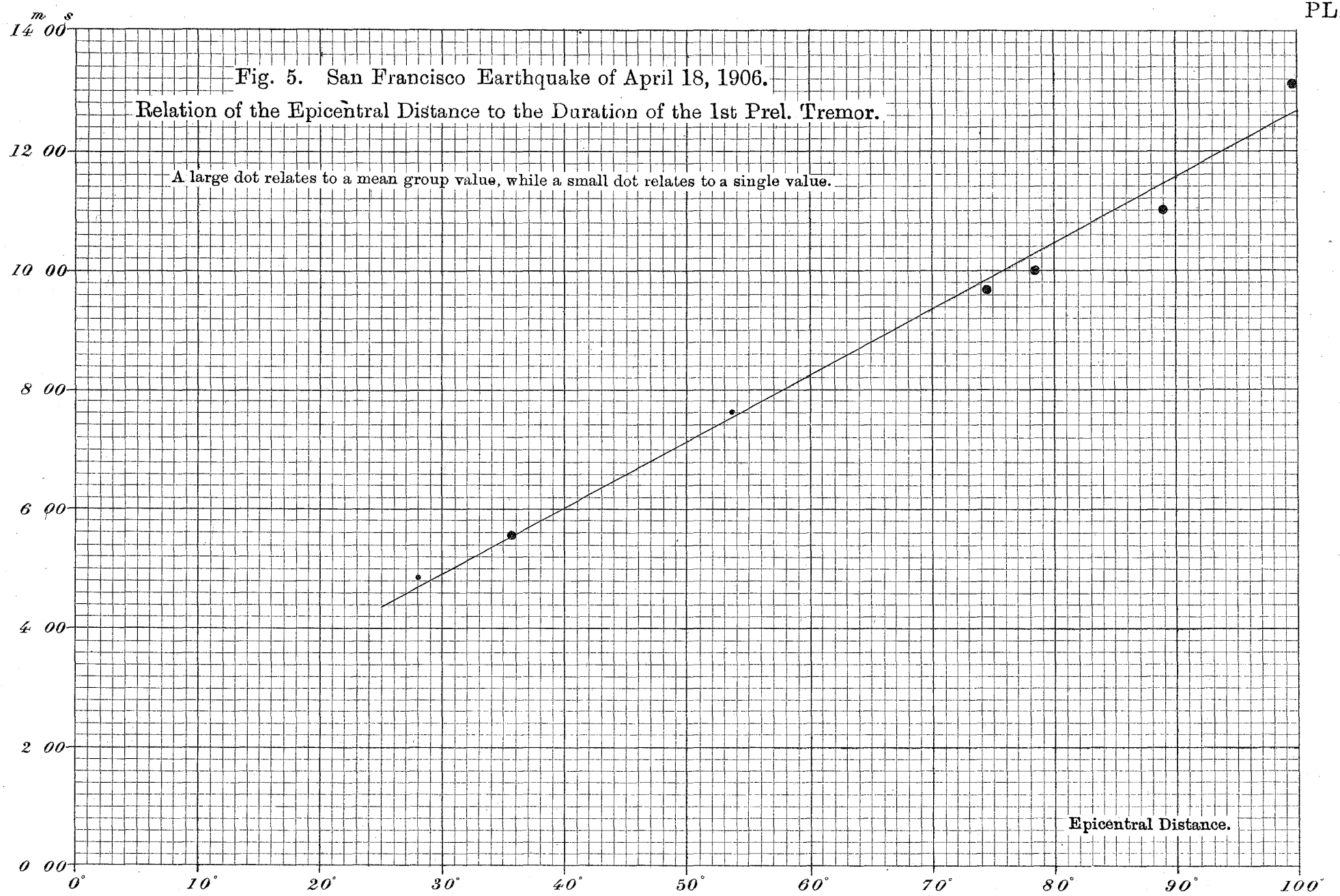


Fig. 5. San Francisco Earthquake of April 18, 1906.

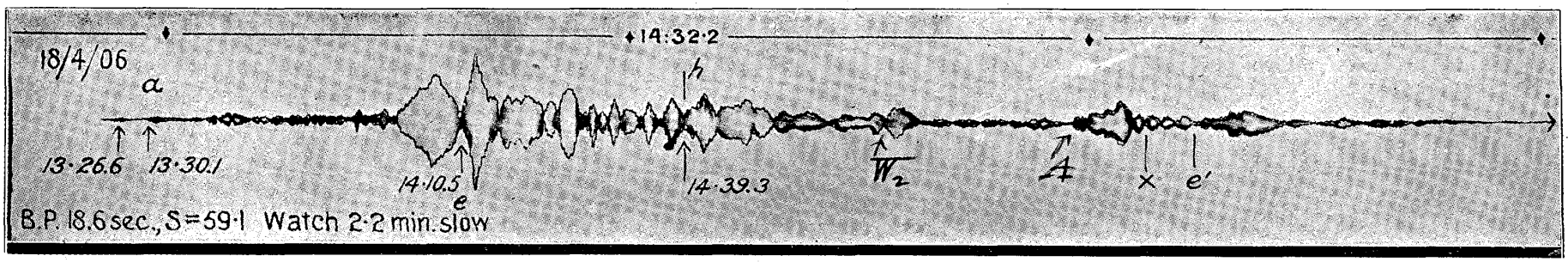
Relation of the Epicentral Distance to the Duration of the 1st Prel. Tremor.

A large dot relates to a mean group value, while a small dot relates to a single value.

SAN FRANCISCO EARTHQUAKE.—RECORD OF MILNE HORIZONTAL SEISMOGRAPH AT WELLINGTON, NEW ZEALAND.

OBSERVER—G. HOGBEN, M.A. [Time, Greenwich mean civil time.]

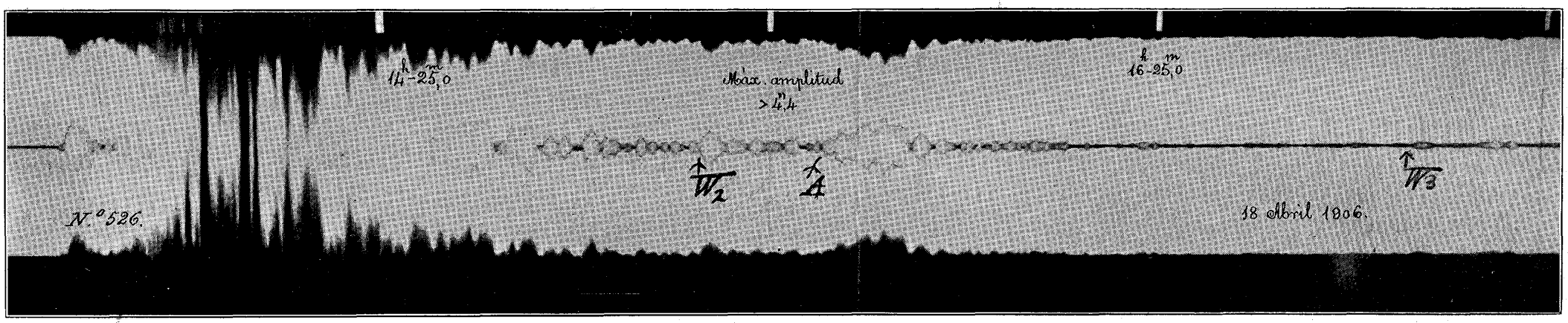
Fig. 6.



The letters denote the waves of the different phases according to Omori's classification: *a*, first phase ("preliminary tremors"); *e*, fifth phase ("long waves"); *e′*, ditto, along the major arc; *h*, eighth phase (probably "transverse waves"); *h′*, ditto, along the major arc. The "repeats" (after successive circuits of the earth) bear the same letters.

SAN FRANCISCO EARTHQUAKE.—RECORD OF MILNE HORIZONTAL PENDULUM SEISMOGRAPH AT THE MARINE OBSERVATORY OF SAN FERNANDO.

Fig. 7.



$=13^h\ 26^m\ 36^s$. The 1st maximum motion, approximately corresponding to the commencement of the principal portion, occurred at $14^h\ 02^m\ 00^s$. The 2nd and largest maximum, which probably corresponded to the 3rd phase of the principal portion, occurring at $14^h\ 10^m\ 30^s$. The 6th phase of the same portion, probably the "transverse" vibration, occurred at $14^h\ 39^m\ 18^s$.

The W_2 motion began at $15^h\ 05^m\ 18^s$; the 1st maximum, which probably corresponded to the commencement of the 3rd phase of the principal portion, occurring at $15^h\ 30^m\ 18^s$. The 2nd maximum occurred at $15^h\ 47^m\ 06^s$.

Comparing the W_1, or the earthquake proper with the W_2 motion, we obtain the following approximate values of the velocities.

Place	Commencement of Princ. Portion.	Commencement of 3rd Phase, Princ. Portion.
San Fernando	4.2 km./sec.	3.7 km./sec.
Wellington	4.8	3.8

These are to be regarded as only gross approximations.

6. The foregoing paragraphs constitute only the preliminary notes on the seismographic observations of the San Francisco earthquake. A full discussion of the transit velocities corresponding to the different phases of the earthquake motion, and the results of the analysis of the seismograms will be given in a future number of the *Publications of the Earthquake Investigation Committee*.