Seismic Triangulation in Tokyo.

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Introduction.

As regards to the velocity of propagation of earthquake waves, numerous observations and experiments have already been performed by several seismologists. The results obtained by General Abbot, Prof. Omori, Dr. Agamennone, and Dr. Cancani, which are important in connection with the subject of the present paper, are given next.

General Abbot, who investigated the earth vibrations caused by the explosion of certain quantities of dynamite, found that the velocity of wave propagation increased with the violence of the initial shock as well as with the sensibility of the instruments used to detect the arrival of earth waves. Thus with a telescope which had a magnification of 12, and at an observing station at a distance of 2.15 km from the position of explosion, 70 and 200 pounds of dynamite gave the velocities of 2.57 and 2.67 km per sec. respectively. With the quantity of 400 pounds of dynamite and at an observing station 1.88 km distant from the origin of shock, the velocity was 2.69 km per sec., while with an enormous quantity of 50000 pounds of the same substance, and at the observing station 13.4 km distant, the velocity was found to be 2.53 km per sec. With a telescope, which had a magnification of 6 and therefore only one-half of that of the former, the velocity obtained was far less. Now the earthquake waves, when they spread to a distant station, become minute and give only a feeble disturbance to the mercury surface there, so that an observer may fail to detect them with a telescope of low magnification, while he may be able to observe them with one of higher magnification. The same reasoning may be applied also to the relation between the velocity and the magnitude of the initial shock. Such a method of observation and experiment will, as a rule, give a value of the transit velocity less than the true one.

From the study of seismograph records obtained in Tokyo, Prof. Omori found the velocity of 2.4 km per sec. in the case of the Mino-Owari earthquake (Oct. 28, 1891) and its after shocks ; 2.3 km per sec. in the case of the Noto earthquakes (Dec. 9 and 11 1891) ; and 1.9 km per sec. in the case of the Nemuro-Kushiro earthquake (March 22, 1894).

Dr. Agamennone, who investigated the 5 earthquakes which occurred in Zante during the first eight months of the year 1893, calculated the time of arrival of the initial wave in the records of seismoscopes at Mineo, of seismographs at Rome, and of horizontal pendulums at Nicolaiew and Strassburg, and obtained for the velocity of propagation the values 3.4, 3.1, 3.8, and 3.5 km per sec. respectively. The same seismologist obtained the values of 3.6, 3.1, and 3.0 km per sec. in the case of the Epirus earthquake, which occurred on the 14th of the same year and was recorded at the above mentioned stations with the exception of Mineo. Dr. Cancani, by a similar method, obtained the value of 3.42 ± 0.13 km per sec. in the case of the Constantinople earthquake of July 10, 1894.

The methods which were adopted by these observers have the objection as already noted. "In an accurate observation of the speed of an earthquake," says Prof. Ewing, "we must be able to identify the same wave in the disturbance as it appears at the different station : not only this but we must be able to identify the same phase of the same wave." For this purpose, he proposed the method of simultaneous observation at three or more stations forming triangles. The same idea was taken up by Prof. Milne, who made the observation between 1884 and 1885 at the ground of Tokyo Engineering College. In Prof. Milne's experiments, however, it was impossible to find the accurate value of the velocity, as the stations were too near to one another. In 1893 Profs. Sekiya and Omori instituted a similar system of observation in an extended scale and a report on the seismic triangulation by Prof. Omori, respecting the focal depth of the earthquake of Nov. 30th 1894, has been given in Vol. XXI of the *Report* (Japanese) of the Imp. Earthquake Investigation Committee. Since the beginning of 1895, the work has been continued by myself, the present paper being a report on the observations made between 1895 and 1898.

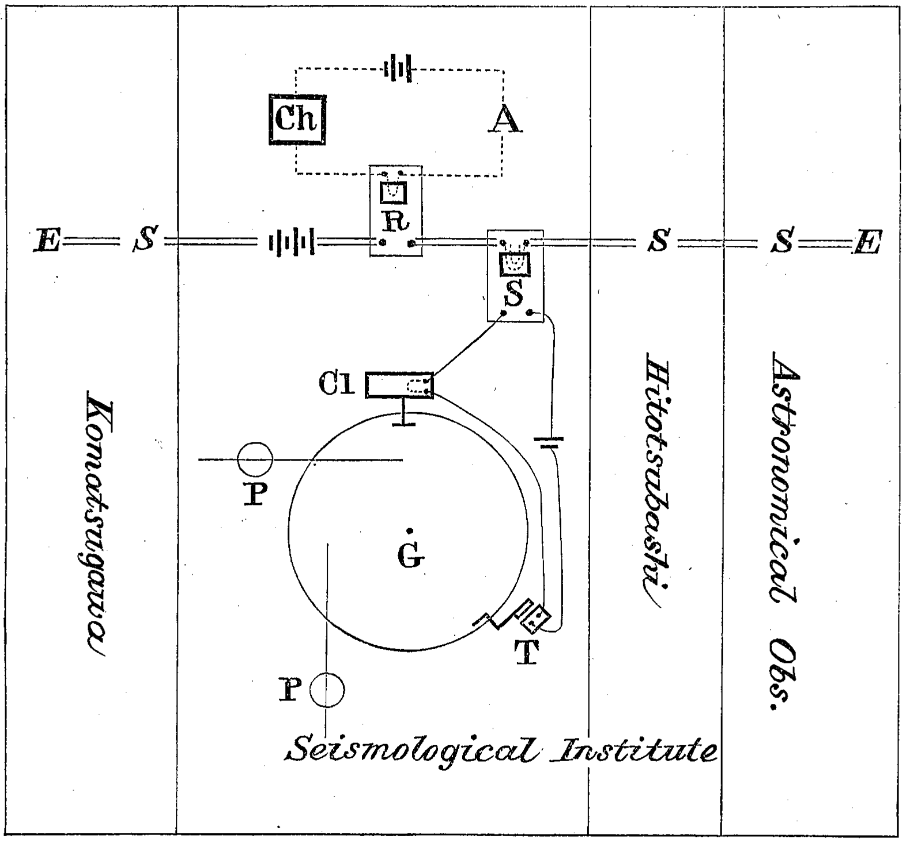
METHOD OF OBSERVATION.

The stations selected by Profs. Sekiya and Omori are the Seismological Institute, the Hitotsubashi Seismological Observatory, the Astronomical Observatory, and the Komatsugawa District Office; the first named being the central station. Each is provided with an Ewing's horizontal pendulum seismograph of the magnification of 5, which writes the motion of the ground in two rectangular components, one in the north and south, and the other in the east and west direction. The seismographs at the different places are connected with a telegraph line, whose two ends pass into earth-plates at the two terminal stations of Komatsugawa and the Astronomical Observatory respectively, and which passes through a galvanometer at each station, a series of electric batteries being kept at the Seismological Institute. Furthar each station is provided with a local circuit which opens at two mercury drops and is so adjusted, when it is closed, as to start a clockwork of the record-receiver and to mark time ticks on the latter with the period of a time-making pendulam, as soon as the circuit of the telegraph line is closed. In case of an earthquake, the latter circuit is closed by the starter at the Seismological Institute, and the needle of the galvanometer at each station is consequently deflected which causes a platinum wire attached to the galvanometer needle to come into contact with the mercury ends and closes the local circuits at the different stations to start the clockworks simultaneously. Under this system of observation, which had been instituted by Profs. Sekiya and Omori, the diagrams of the earthquakes No. 1—No. 4 were obtained.

In order to get a correct value of the velocity as far as its second figures are concerned, we must be able to measure the times of arrival as accurately as one hundredth of a second, for there was an example in which this time differences amounted only to a second. Now the period of each of the time-ticker pendulums which was repeatedly determined and found to be between 0.7 and 0.8 sec., might be subject to an error amounting to one hundredth of a second or even more. If, therefore, the wave taken for identification was one which occurred more than 10 seconds after the instruments had started, the error in the time differences might sometimes amount to one-tenth of a second. To this must be added an error which may arise from the unequal effects of earthquake disturbances at the different stations on swing of the pendulums. The objection, however, applies very little in our cases, as the waves for identification were always taken at the beginning of the principal motion, which appeared at most in 5 seconds after the start. If the waves taken for identification were ones which appeared some time not less than ten seconds after the start, the value of the velocity thus obtained would be inaccurate. It was therefore necessary to change the arrangement in order to get rid of such defect, which was practicated in the spring of 1897. The new arrangement is illustrated in the accompanying wood-cut.

The line B opens at the relay points R at the Seismological Institute and passes through sounders S at each of the different stations, and terminates in the earthplates E at the Astronomical Observatory and Komatsugawa. Each local circuit containing a time-ticker T, and a clockwork Cl, opens at the sounder, but is closed in the instant when the line circuit is closed. The chronometer circuit at the Seismological Institute contains a chronometer Ch and the relay R, and opens at an arrangement A which is to close this circuit for about 40 seconds after the commencement of an earthquake.

This is to avoid a confusion of the time record in the record receiver. Thus at the occurrence of an earthquake the chronometer circuit is closed at first, and subsequently the line circuit and the different local



·········Ch circuit, ——local circuit, =line *B*.

circuit at once. As soon as the record receivers are started the periodic breaking of circuit at the chronometer is transmitted through the different circuits, the chronometer seconds being simultaneously recorded at each of the stations. In this way, the earthquake records No. 5—No. 8 were obtained.

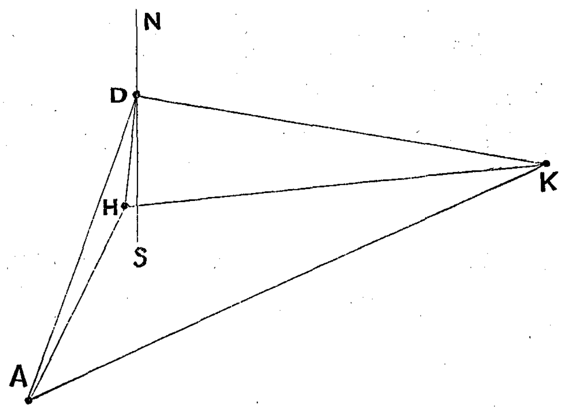
I wish to mention here one of causes of failure in getting the seismograms in cases of earthquakes. Near the telegraph line connecting the stations, there are a great number of the similar lines running parallel with ours. When one of these lines touches our line a part of the latter lying between the point of contact and the nearest earthplate acts as shunt to the circuit of the former, and the instruments in this part begins to start. Such disturbances occurred very frequently, until my *mechanical starter* was inserted in the line at each of the earthplate stations. The description of the *starter* is given later on.

RESULTS OF OBSERVATION.

In comparing the seismograms recorded at the earthquake triangulation stations, it was sometimes found that the waves, which occurred some seconds after the initial principal motion had different characters at the different stations, while such was not the case with those at the commencement of the principal motion. This fact is probably due partly to the different modes of oscillation at the different stations and partly to the existence of more or less proper oscillation of the *steady masses* of the horizontal pendulums. Consequently I have selected for identification the waves at the commencement of the principal motion. Let us now consider how to find the differences of time in which a given earthquake wave arrives at the different stations. If the distance of an earthquake origin from the stations be very large in comparison to the mutual distances between the latter, we can determine by a simple ratio of the differences of time of arrival the direction of propagation as well as its velocity; the directions of propagation of the disturbance at the different stations being practically parallel to one another. In each case, moreover, the approximate position of the epicentre, can he found by means of earthquake reports from the various parts of the country which are systematically sent in to the Central Meteorological Observatory. The direction of propagation of the seismic waves was determined by these two methods, the result agreeing in each case within a few degrees of angle. In the case of earthquake No. 6, the direction of propagation was determined from the report of the Central Meteorological Observatory, as the seismograms were obtained only at two of our stations which did not enable us to determine the direction.

The positions and relative distances of the four earthquake triangulation stations are as follows :—

Station.	Longitude, E.	Latitude, N.
D, Seismological Institute	139° 45′ 51″	35° 42′ 33″
H, Hitotsubashi	139° 45′ 33″	35° 41′ 20″
A, Astronomical Observatory	139° 44′ 30″	35° 39′ 18″
K, Komatsugawa	138° 51′ 7″	35° 41′ 38″



Distance	Km.
Seismological Institute—Hitotsubashi	2·30
,, ,, —Astronomical Observatory	6·36
,, ,, —Komatsugawa	8·13
Hitotsubashi—Astronomical Observatory	4·09
,, —Komatsugawa	8·42
Astronomical Observatory—Komatsugawa	10·92

Let NS in the figure be the north and south line through the Seismological Institute, then

$SDH = 12°3$, $SDA = 19°2$, $DAH = 4°0$

$ADK = 97°1$, $DAS = 47°4$.

Referred to the east and west line and north and south line through the Astronomical Observatory as axes, the coordinates of each station are as follows :—

	Km.	Km.
Seismological Institute	2·09,	6·01,
Hitotsubashi	1·61,	3·76,
Astronomical Observatory	0,	0,
Komatsugawa............................	10·02,	4·34.

The above numerical measurements are based on the newly revised $\frac{1}{200000}$ maps issued by the Department of Survey, General Staff, and the lately determined coordinates of the Tokyo Astronomical Observatory.

No. 1. Earthquake of April 3, 1895. This earthquake was recorded at the Seismological Institute, Hitotsubashi, and Astronomical Observatory. The observations at the Meteorological Observatories were as follows :—

Met. Station.	Time of occurrence.			Intensity.	Direction.
Tokyo	19h	49m	44s	Weak	*NW–SE.*
Kofu	,,	,,	54s	,,	*NWW–SEE.*
Utsunomiya	,,	,,	1s	,,	*E–W.*
Ishinomaki	,,	50m	40s	,,	——
Fukushima	,,	,,	2s	Slight	*SW–NE.*
Niigata	,,	,,	27s	,,	——
Choshi	,,	,,	—	,,	——
Nagoya	,,	56m	40s	,,	*E–W.*
Hikone	,,	50m	14s	,,	——

According to the above observations, the position of the epicentre appears to have been at a distance of 110km in the direction *N* 35° *W* from Tokyo.

In our seismograms, the wave at the commencement of the principal motion was taken for identification. Let us hereafter call the wave for indentification in the seismograms of the *EW* component *A*, and that of the *NS* component *B*. The result of the observations is as follows :—

Station.	Number of ticks from start.		Average.	Tick period.	Time (in seconds) from start.
	A	B			
Astro. Obs.	—	4.17	4s.17	0.74	3.09
Hitotsubashi	2.94	3.02	2.98	0.77	2.30
Seismological Institute	2.35	2.37	2.36	$\frac{30}{40.5}$	1.74

The above data give the direction of propagation *N* 27°7 *W*, and the velocity of 3.22 km per sec. As the disturbance was not large enough, it was not possible to examine whether the direction of propagation and that of the earthquake movements agreed or not.

No. 2. Earthquake of Feb. 23, 1896. This was recorded at all the four stations. The report of the Central Meteorological Observatory is as follows:—

Met. Station.	Time of occurrence.			Intensity.	Direction.	Nature.
Tokyo	19h	41m	47s	Weak	*NW–SE*	Gentle.
Choshi		42m	0	,,	—	—
Yokosuga		,,	32s	,,	—	—
Utsunomiya		43m	0	,,	—	—
Ishinomaki		,,	,,	,,	—	—
Fukushima		57m	47s	,,	—	—
Kofu		41m	37s	Slight	—	—
Nagano		,,	55s	,,	—	—
Miyako		42m	10s	,,	—	—
Numatsu		,,	,,	,,	—	—
Niigata		,,	29s	,,	—	—
Nagoya		43m	0	,,	—	—
Yamakata		47m	40s	,,	—	—

The position of the epicentre appears to have been at a distance of about 160 km in the direction *N* 35° *E* from Tokyo.

In our records, the wave at the beginning of the principal motion in the *EW* component was taken for comparison.

Station.	Number of ticks from start.	Tick period.	Time from start.
Seismological Institute	5·95	0^s·675	4^s·02
Hitotsubashi	5·94	0·785	4·66
Astro. Obs.	7·77	0·745	5·80
Komatsugawa	4·90	0·771	3·77

The above data give the direction of propagation N 18°2 E and the transit velocity of 3·58 km per sec.

No. 3. Earthquake of March 6, 1896. This was recorded at all the four stations. The report of the Central Meteorological Observatory is as follows :—

Met. Station.	Time of occurrence.			Intensity.	Direction.
Yokosuga	23h	50m	23s	Weak	——
Kofu	,,	,,	36s	,,	*NW–SE.*
Numatsu	,,	51m	25s	,,	*SE–NW*
Utsunomiya	,,	51m	30s	,,	*SWW–NEE*
Tokyo	,,	,,	31s	,,	*SW–NE*
Fukushima	,,	,,	32s	,,	*N–S*
Nagano	,,	,,	21s	Slight	——
Nagoya	,,	52m	28s	,,	*NE–SW*
Hikone	,,	53m	55s	,,	——
Yamakata	,,	52m	0s	,,	——
Chōshi	,,	52m	0s	,,	*SE–SW*

The approximate position of the epicentre was at a distance of 120 km to *N* 20° *E* from Tokyo.

In our records, the waves in the *NS* component and B in the *EW* component were taken for identification.

Station.	Number of ticks from start.		Tick period.	Time from start	
	A	B		A	B
			s	s	s
Astro. Obs.	6·41	6·81	$\frac{195}{245}$	5·10	5·42
Hitotsubashi	4·92	5·24	$\frac{153}{195}$	3·80	4·11
Komatsugawa	4·35	4·50	$\frac{135}{175}$	3·41	3·47
Seismological Institute	4·06	4·26	$\frac{29}{38}$	3·10	3·25

Of the wave A, the direction of propagation and the velocity were determined to be *N* 6°·0 *E* and 3·10 km per sec. respectively; while of the wave B these were found to be *N* 8°8 *E* and 3·16 km per sec. respectively. The direction of the earthquake movement and that of the wave propagation did not differ by more than 15°.

No. 4. Earthquake of April 24, 1896. This earthquake was recorded at the central station, Hitotsubashi, and the Astronomical Observatory. The report of the Central Meteorological Observatory is as follows:—

Met. Station.	Time of occurrence.			Intensity.	Direction.
Kōfu	10h	50m	17s	Strong	*NE-SW*
Tokyo	,,	49m	56s	Weak	*SSE-NWW*
Yokosuga	,,	49m	58s	,,	——
Chōshi	,,	50m	0s	,,	*SWW-NEE*
Utsunomiya	,,	50m	7s	,,	*SSW-NNE*
Numatsu	,,	50m	19s	Slight	——
Gifu	,,	51m	31s	,,	——
Fukushima	,,	48m	52s	,,	*SW-NE*
Aomori	,,	49m	40s	,,	——
Hikone	,,	51m	2s	,,	——
Yamakata	,,	53m	20s	,,	——

The epicentre was approximately at a distance of 70 km in the direction *N* 25° *W*.

In our records, the waves A in the *NS* component and *B* in the *EW* component were compared.

Station.	Number of ticks from start.			Tick period.	Time from start.
	A	B	Average.		
				s	s
Astro. Obs.	4·00	3·91	3·96	144/185	3.08
Hitotsubashi	2·88	2·76	2·82	104/135	2.17
Seismological Institute	2·17	1·95	2·06	140/185	1·56

The data give the direction of propagation $N\ 24°\ 3\ W$ and the transit velocity of 3·04 km per sec. The direction of propagation and the direction of movement agreed fairly well with each other.

No. 5. Earthquake of Aug. 5, 1897. This was recorded at the Seismological Institute, Hitotsubashi, and the Astronomical Observatory. The report of the Central Meteorological Observatory is as follwows :—

Met. Station.	Time of occurrence.			Intensity.	Direction.	Nature.
Kumagae	9h	7m	33s	Strong	——	Gentle.
Ishinomaki	,,	10m	30s	,,	*NNW-SSE*	Vertical motion developed.
Mito	,,	10m	55s	,,	——	,,
Aomori	,,	11m	40s	,,	*SE-NW*	,,
Yamakata	,,	11m	50s	,,	*SE-NW*	v. m. developed, houses trembled.
Maebashi	,,	11m	55s	,,	——	Sharp, v. m. developed.
Yokohama	,,	11m	56s	,,	——	——
Niigata	,,	12m	20s	,,	——	v. m. developed.
Kōfu	,,	12m	57s	,,	——	——
Fukushima	,,	10m	15s	Weak	——	——

Met. Station.	Time of occurrence.			Intensity.	Direction.	Nature.
Nagano	9h	11m	11s	Weak	—	—
Gifu	,,	11m	26s	,,	—	—
Utsunomiya	,,	12m	10s	,,	—	Long.
Tokyo	,,	12m	23s	,,	—	Gentle.
Yokosuga	,,	12m	27s	,,	—	—
Nagoya	,,	13m	4s	,,	—	—
Akita	,,	20m	20s	,,	—	—
Chōshi	,,	12m	0s	,,	—	—
Numatsu	,,	12m	7s	,,	—	—
Nemuro	,,	12m	20s	,,	—	—
Kushiro	,,	13m	40s	,,	—	—
Yaki	,,	15m	50s	,,	—	—
Miyako	,,	—	—	—	*SEE–NWW*	—

This earthquake caused sea-waves along the eastern coast of Rikuzen, their nature resembling in every respect to those of the large sea-waves on the 15th of June, 1896, except their heights whose maximum amount were in the present case only 2 or 3 meters. From this fact and from the observations at the meteorological stations given above we may fix the position of the epicentre which was submarine, at approximately lat. 38° 5 *N* and long. 143° 5 E., namely at a distance of 450 km in to *N* 50° *E* from Tokyo.

In the seismograms obtained at our stations, the wave A in the *EW* component was compared.

Station.	Time interval from start.
Astro. Obs.	s 15·29
Hitotsubashi	14·33
Seismological Institute	13·89

These data give the direction of propagation *N* 63° 9 *E* and the velocity of 3·23 km per sec.

No. 6. Earthquake of Aug. 16, 1897. This was recorded at the Seismological Institute and Hitotsubashi. The report of Central Meteorological Observatory is as follows :—

Met. Station.	Time of occurrence.			Intensity.	Direction.	Nature.
Aomori	16h	53m	0s	Strong	*SE–NW*	Gentle (weak).
Fukushima	,,	48m	25s	Weak	*SSW–NNE*	v. m. developed, houses trembled.
Chōshi	,,	50m	27s	,,	—	Long (slight).
Mito	,,	52m	46s	,,	—	v. m. developed, houses trembled.
Yamakata	,,	53m	0s	,,	—	Houses trembled.
Miyako	,,	,,	3s	,,	*W–E*	v. m. developed, houses trembled.
Maebashi	,,	,,	22s	,,	—	Sharp, v. m. developed, (slight),
Tokyo	,,	,,	33s	,,	—	Gentle. (slight),
Kumagai	,,	,,	50s	,,	—	,, ,, Gentle.
Hakodate	,,	54m	25s	,,	—	v. m. developed, (slight),
Yokosuga	,,	,,	28s	,,	—	Gentle. (slight),
Utsunomiya	,,	55m	1s	,,	—	Gentle.
Akita	,,	,,	20s	,,	—	v. m. developed.
Ishinomaki	,,	,,	25s	,,	—	v. m. developed, houses trembled.

Met. Station.	Time of occurrence.	Intensity.	Direction.	Nature.
Fukui	16h 49m 0s	Slight	—	—
Nagoya	„ 54m 12s	„	—	Long.
Yokohama	„ 55m 28s	„	—	Gentle.
Gitu	„ 57m 38s	„	—	

The epicentre was approximately at a distance of 300 km in the direction of *N* 42° *E.* from Tokyo.

In our records, the waves A and B in the *NS* component were compared.

Station.	Time from start.	
	A	B
	s	s
Hitotsubashi	12·35	13·00
Seismological Institute	11·74	12·39

The time difference was thus 0·61 second, and we obtain the velocity of 3.20 per sec.

No. 7. Earthquake of Feb. 13,1898. This was recorded at all the four stations. The report of the Central Meteorological Observatory is as follows :—

Met. Station.	Time of occurrence.	Intensity.	Direction.	Nature.
Kumagai	23h 58m 13s	Strong	—	Sharp.
Maebashi	„ „ 27s	Weak	—	—
Yokohama	„ „ 34s	Strong	—	Sharp.
Tokyo	„ „ 36s	Weak	*SSE–NNW*	Sharp.
Yokosuga	„ „ 45s	Strong	—	Sharp.
Utsunomiya	„ „ 46s	Strong	*SEE–NWW*	Sharp, v. m. developted, houses trembled.
Kofu	„ „ 55s	Weak	—	Sharp, hauses trembled.

Met. Station.	Time of occurrence.			Intensity.	Direction.	Nature.
Numatsu	23h	59m	0s	Weak	—	—
Mito	,,	59m	5s	Weak	—	v. m. developed.
Chōshi	,,	58m	0s	Slight	—	Gentle.
Niigata	,,	,,	46s	,,	—	,,
Yamkata	,,	59m	0s	,,	—	,,
Ishinomaki	,,	,,	60s	,,	—	,,
Gifu	,,	,,	14s	,,	—	,,
Nagoya	,,	,,	41s	,,	—	,,

The position of the epicentre was approximately at a distance of 60 km to the *N* 25° *W* of Tokyo.

In our records, the waves A in the *NS* component, and B in the *EW* component were compared.

Station.	Time from start.		
	A	*B*	Average.
	s	s	s
Komatsugawa	7.95	8.56	8.26
Astro. Obs.	7.64	8.35	7.99
Hitotsubashi	6.89	7.63	7.26
Seismological Institute	6.43	7.08	6.76

From the time difference of the waves the direction of propagation is found to be *N* 29° 2 *W* and the velocity 3·51 km per sec. Similarly from the wave B, the values come out to be *N* 27°7 *W* and 3·46 km per sec. On average, therefore the direction of propagation was *N* 28° 5 *W* and the velocity 3·49 km. per sec. The direction of movement and the direction of propagation agreed very well with each other.

No. 8. Earthquake of July 12, 1898. This was recorded at all the stations. The report of the Central Meteorological Observatory is as follows:—

Met. Station.	Time of occurrence.			Intensity.	Direction.	Nature.
Tokyo	22h	55m	35s	Weak	*SW–NE*	—
Yokohama	,,	56m	19s	,,	—	Gentle.
Utsunomiya	,,	55m	30s	,,	—	—
Ishinomaki	,,	55m	30s	,,	—	—
Yokosuga	,,	56m	20s	,,	—	Accompanied by sound.
Mito	,,	56m	32s	,,	—	Sharp.
Matsumoto	,,	56m	10s	Slight	—	—
Gifu	,,	56m	15s	,,	—	—
Fukui	,,	56m	23s	,,	—	—
Nagoya	,,	56m	54s	,,	—	Gentle.
Kumagae	,,	57m	3s	,,	—	,,
Kōfu	,,	57m	30s	,,	—	,,
Miyako	,,	58m	43s	,,	—	—

The epicentre was approximately at a distance of 80 km in the direction N 45° W from Tokyo.

In our records, the wave near the commencement of the proper motion in the EW component was compared.

Station.	Time from start.
Seismological Institute	s 3·26
Hitotsubashi	3·67
Astro. Obs.	4·20
Komatsugawa	5·21

From these data the direction of propagation is found to be N 40.°9 W and the velocity of propagation 3·30 km per sec. Except at the Astronomical Observatory, the direction of the earthquake motion agreed nearly with that of propagation.

In the present series of the calculation of the velocity and direction of propagation, it has been assumed that the seismic disturbances spread from the epicentres. The velocity found in this way refers therefore to what may be called the surface velocity of earthquake propagation; and in finding the real velocity, a correction arising from the depth of the earthquake centres must be introduced. The latter correction is necessary in the case of an earthquake whose epicentre is near to the stations. If we call the angle of emergence θ, and the real and surface velocities V and V' respectively, the relation $V=V' \cos\theta$ holds approximately. As there is no suitable means for the determination of the depth, we must be content with the value of the angle of emergence which may be roughly determined from the horizontal and the vertical components of the earthquake motion recorded in Tokyo. Our instruments, however, were provided with no vertical seismograph, so I took the maximum values of the two components at the Central Meteorological Observatory. The vertical component motion is usually very small in comparison to the horizontal, so that it is unnecessary to introduce the correction into the value of the velocity. In the present cases, however we found that the earthquakes No. 3 and No. 7 are to be treated in a different way, for in the former the vertical and the horizontal components were respectively 0·4 mm. and 4·3 mm., while in the latter they were 0·5 mm. and 1·4 mm. Thus we have

$$V=3{\cdot}13 \cos\left(\text{arc tan } \tfrac{4}{43}\right)=3{\cdot}11 \text{ km} \ldots\ldots \text{Eqke. No. 3,}$$

$$V=3{\cdot}49 \cos\left(\text{arc tan } \tfrac{5}{14}\right)=3{\cdot}28 \text{ km} \ldots\ldots \quad ,, \quad \text{No. 7.}$$

Such modifications are, however, very doubtful, so it is perhaps better to adopt the original values of the velocity as already given. Tabulating all the results, we have

No.	Date.	Stations.	Distance of epicentre.	Velocity.
			km.	
1	April 3, 1895.	S.H.A.	110	3·22
2	Feb. 23, 1896.	S.H.A.K.	160	3·58
3	March, 6, 1896.	S.H.A.K.	120	3·13
4	April 24, 1896.	S.H.A.	70	3·04
5	Aug. 5, 1897.	S.H.A.	450	3·23
6	Aug. 16, 1897.	S.H.	300	3·26
7	Feb. 13, 1898.	S.H.A.K.	60	3·49
8	July 12, 1898.	S.H.A.K.	80	3·30

Taking the number of identified waves in each case as the weight of the corresponding result, the average value of the velocity of propagation in second and kilometer is as follows :—

$$V = 3{\cdot}28 \pm 0{\cdot}05.$$

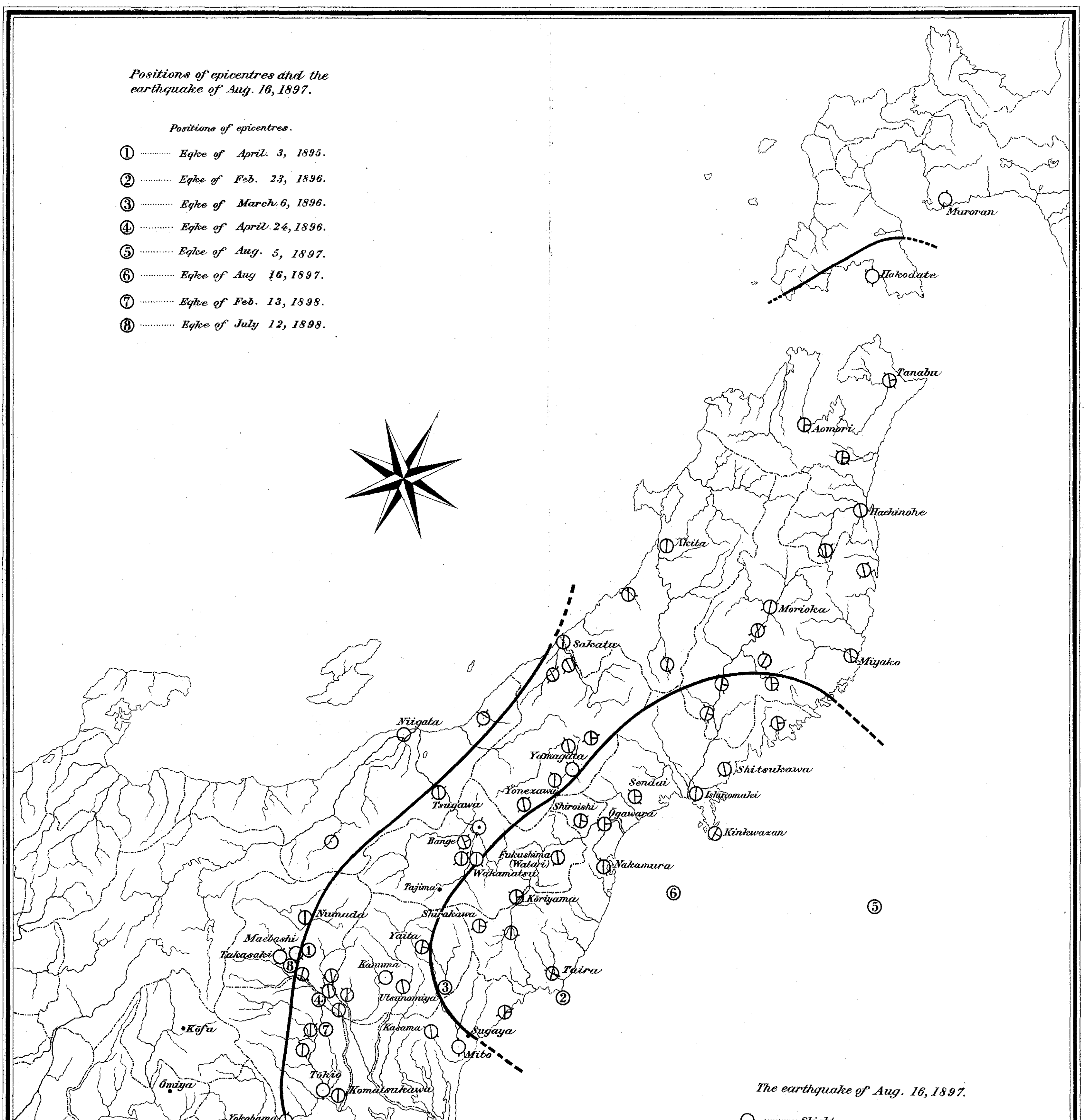
As the third figure has but little weight, the value 3·3 kilometers per second may be taken as being practically correct.

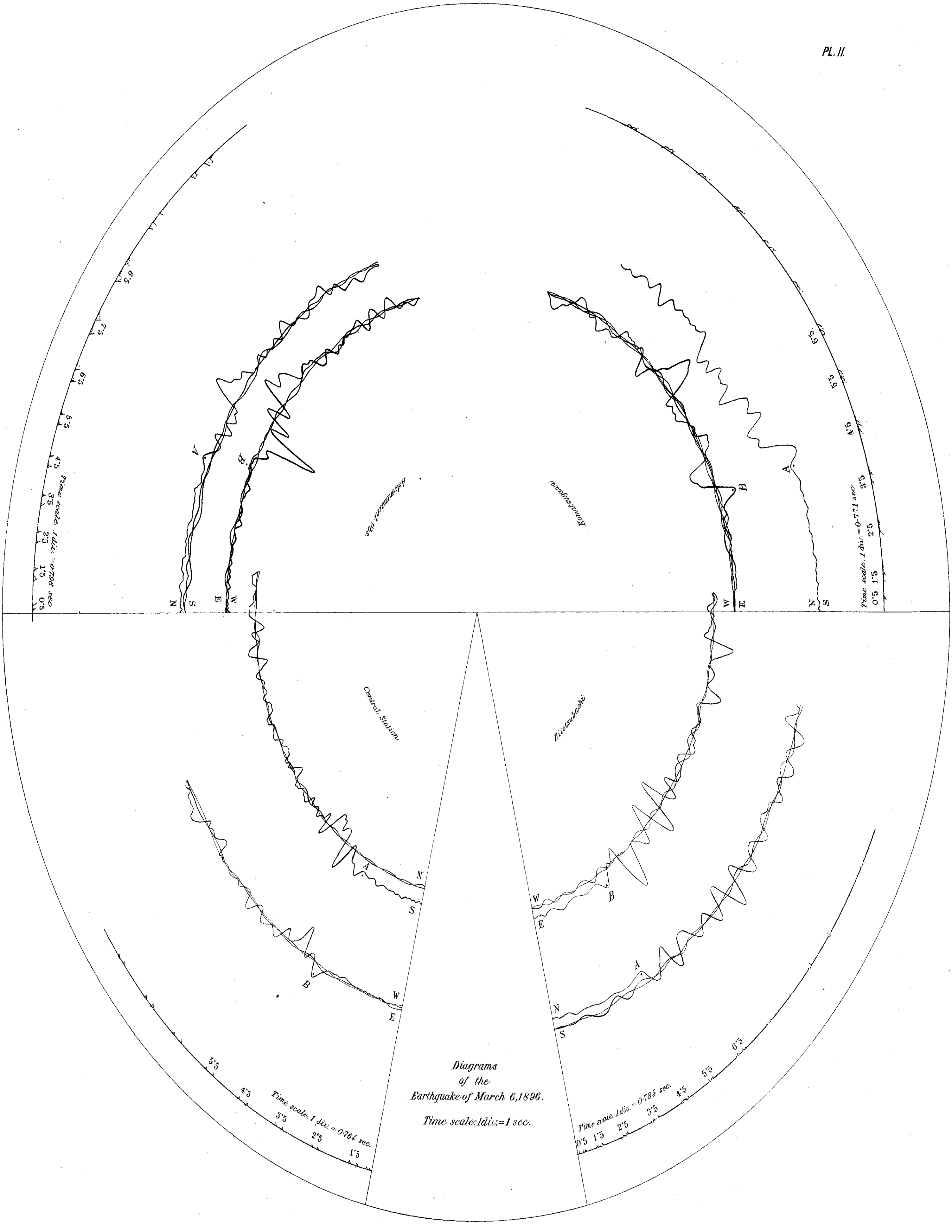
As regard to the question, whether the value of the velocity is different for different localities, there is a reason to think that such relation does not exists, as far as the degree of accuracy of the value of the velocity, which the present system of observation can give, is concerned. Thus we may suppose that the earth strata on which our different stations stand lie almost horizontally one upon another. From the study of the elastic constants of rocks, Prof. Nagaoka gives the view that there is a stratum of maximum velocity of propagation. If this stratum be not too deep, as he suggests, earthquake waves originating at some distance will travel along this stratum and will be refracted to each of our different stations before the arrival of the waves through other media, so that the velocity of propagation which we have obtained will be one in such stratum and not in the superficial soil.

It was found by Prof. Omori that earthquakes, when registered by means of sensitive and long period pendulum seismographs at distant stations, give for the waves at the beginning of the preliminary tremor a transit velocity as high as 13 km per sec., but for the waves at the commencement of the principal and quick period motion a velocity of only about 3·3 km. The latter velocity corresponds to the result obtained in our case, as the waves taken for comparison were those which formed the principal part of earthquake motion.

Lastly, the direction of the principal motion, when well defined, coincided generally with that of propagation of earthquake waves. Different seismologists have shown that the principal movements of the ground in cases of certain destructive earthquakes consisted mainly of the normal waves; and here we arrive at the same conclusion in cases of moderate shocks.

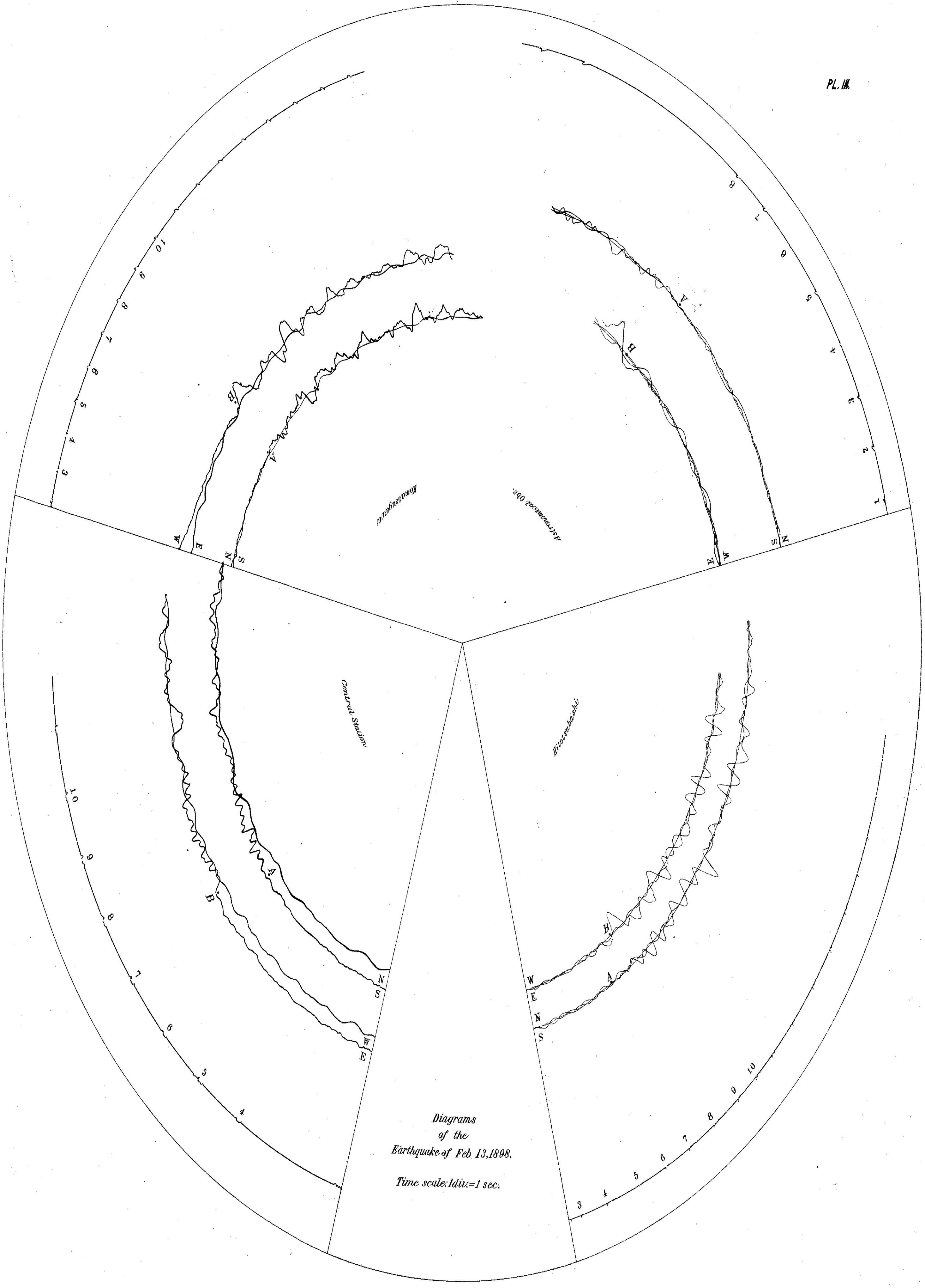
Tokyo. December, 1899.


Positions of epicentres and the earthquake of Aug. 16, 1897.
Positions of epicentres.
① Eqke of April 3, 1895.
② Eqke of Feb. 23, 1896.
③ Eqke of March 6, 1896.
④ Eqke of April 24, 1896.
⑤ Eqke of Aug. 5, 1897.
⑥ Eqke of Aug 16, 1897.
⑦ Eqke of Feb. 13, 1898.
⑧ Eqke of July 12, 1898.
The earthquake of Aug. 16, 1897.
Slight
Rather weak
Weak.
Strong.
Direction
Muroran
Hakodate
Tanabu
Aomori
Hachinohe
Akita
Morioka
Miyako
Sakata
Niigata
Yamagata
Shitsukawa
Sendai
Yonezawa
Ishinomaki
Tsugawa
Shiroishi
Ogawara
Kinkwazan
Bange
Fukushima (Watari)
Wakamatsu
Nakamura
Tajima
Koriyama
Numuda
Shirakawa
Maebashi
Yaita
Takasaki
Kanuma
Taira
Utsunomiya
Kofu
Kasama
Sugaya
Mito
Tokio
Omiya
Komatsukawa
Yokohama
Numatsu
Sakura
Yokosuga
Kwannonzaki
Choshi
Kengasaki
Kisaratsu



Diagrams
of the
Earthquake of March 6, 1896.

Time scale: 1 div. = 1 sec.


Komabugawa
Astronomical Obs.
Central Station
Hitotsubashi
A
B
W
E
N
S
Diagrams
of the
Earthquake of Feb. 13, 1898.
Time scale: 1div.=1 sec.