Note on the Tokyo Earthquake of June 20th 1894.

BY

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1.—The earthquake of June 20th 1894 is the most violent that has shaken Tokyo since the great catastrophe of the 2nd year of the Ansei period (1855). The land area in which the motion was sufficiently strong to be felt without instrumental aid was about 110,000 sq. km, the mean radius of propagation being about 300 km. In Tokyo many brick buildings were severely damaged, chimneys in particular having been mostly thrown down; some *dozo* (godowns) had their plastered mud walls very much cracked and shaken down, tomb-stones and *ishidoro* (stone lanterns for gardens) were overturned, small cracks were formed in the ground, and in a few cases water was ejected. The number of casualties in the three Prefectures of Tokyo, Kanagawa and Saitama were 26 persons killed and 171 wounded.

2.—The maximum acceleration of the earthquake motion in the low and soft-ground portions of Tokyo, such as Tsukiji, Honjō, Fukagawa and Shiba, was, judging from the bodies overturned, about 1000 mm per sec. per sec., which is equal to $\frac{10}{26}$th of the intensity at Nagoya of the great Mino-Owari earthquake of 1891, and a little less than that at the epicentres of the earthquakes of Kumamoto of 1889, and of Kagoshima of 1893. The radii of propagation of the three last earthquakes were respectively 520, 180 and 160 km.

The intensity of motion in the high and hard-ground portions of Tokyo was about half of that in the districts already named.

3.—The meizoseismal tract, or the epifocus, was a zone which extends in nearly NS direction from the vicinity of the town of Iwatsuki to the eastern part of Tokyo. The earthquake origin thus seems to have been formed under the lowest part of the Musashi plane, which forms the continuation of the axis of Tokyo Bay, and has apparently no connection with the famous fault line, extending from the northern part of the province of Awa to the Miura Peninsula of the province of Sagami.

The earthquake was a little milder at Yokohama than in Tokyo, the intensity becoming still weaker towards the south at Kamakura, where no particular damage was produced. Towards the north, the shock was very strong at the towns of Soka, Hotogaya and Kawaguchi, where the intensity was nearly the same as in the low parts of Tokyo.

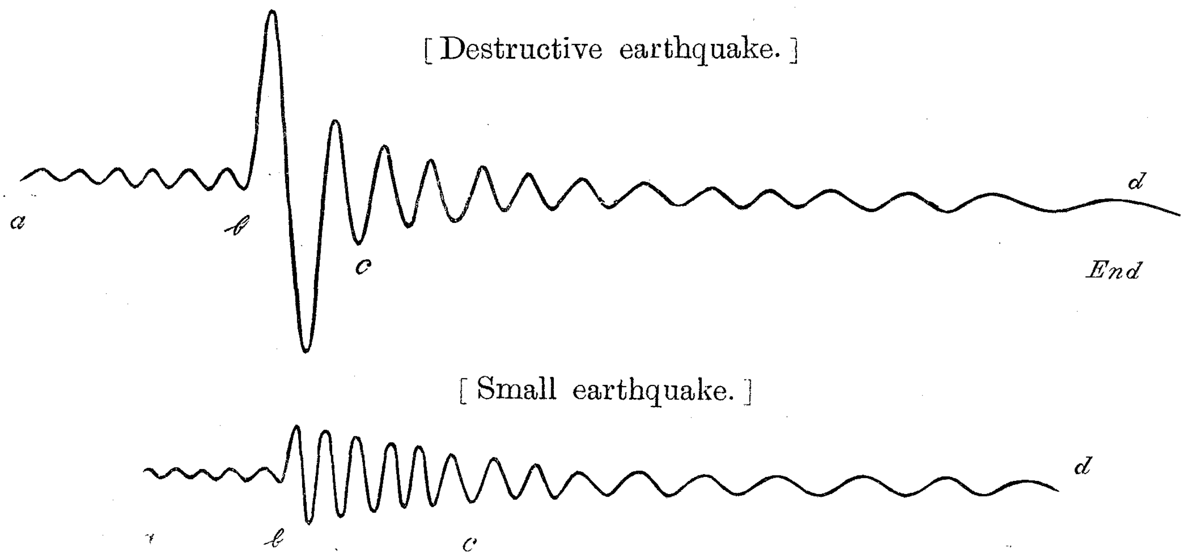
4.—As will be seen from §§ 1 and 2, the magnitude or the extent of this earthquake was much greater than those of the earthquakes of Kumamoto and Kagoshima. Its epifocal intensity of motion was however less than that of the last two shocks. It thus appears that the origin of the Tokyo earthquake was comparatively very deep.

5.—The earthquake was, unlike other destructive ones, followed by only a few after-shocks. This apparent anomaly is however easily explained by assuming the depth of the earthquake origin to be so great that the after-shocks mostly did not reach the epifocus. (See § 4.) On the night succeeding the earthquake, I observed a tromometer, or exceedingly sensitive seismoscope from time to time, but the ground was found to be already perfectly calm.

6.—The earthquake was satisfactorily recorded by a strong-motion seismograph set up in the Seismological Institute (Hongo, Tokyo). According to the diagram,* the maximum horizontal motion was 73 mm, while the maximum vertical motion was only 10 mm. The damage to buildings, chimneys, etc., was therefore practically caused by the horizontal motion only.

The character of the earthquake motion was very simple, the preliminary tremor having been followed at once by the single maximum vibration, which was much larger than the rest of the motion. I believe the motion in the meizoseismal area of destructive earthquakes to be generally of this type, and not necessarily so complicated as at great distances from the origin. In the case of small ordinary earthquakes, there is no single prominent displacement, the motion consisting of a great number of vibrations of nearly equal amplitude. (See the accompanying figure.)

DIAGRAMS ILLUSTRATING THE EARTHQUAKE MOTION.



ab.........The Preliminary tremor.
bc.........The Principal portion.
cd.........The End portion.

* The diagram, originally published by the late Prof. S. Sekiya and myself in Vol. VII of the Jour. Coll. Sc. Imp. Univ. of Tokyo, is reproduced in the following paper.

It is probable that the motion in small earthquakes consists of nearly pure elastic vibrations of the material constituting the earth's crust; while the principal motion in destructive earthquakes is beyond the elastic limit of the latter and consequently is rapidly diminished.

The simple character of the motion naturally implies the existence of a definite direction in the earthquake. The maximum motion in the Tokyo shock under consideration was directed towards S 70° W.

7.—In connection with the direction of the earthquake motion, I observed in different parts of the city of Tokyo 224 cases of overturning of stone lanterns, of which 152 had cylindrical stems, and the remaining 72 square stems. Besides these, there were 21 cases of projection, or overthrowing of the tops of stone lanterns and tomb-stones. The results of the observation are given in table I.

TABLE I.—Directions of overturning of stone lanterns and tomb-stones observed in different parts of Tokyo.

(a) 152 stone lanterns with cylindrical stems.

(Fukagawa.)	W	N 25° E	S 40° W
	S 60° W	N 80° E	N 40° W
N 80° W	S 80° W	N 50° E	S 40° W
N 80° W	N 20° E	S 65° W	N 50° W
S 80° W	S 65° W	S 65° W	SW
W	W	SW	SW
S 60° W	N 85° W	SW	S 80° W
S 45° W	S 80° W	W	N
S 20° E	S 60° W	S 20° E	N 25° E
S 25° W	S 85° W	N 45° E	SE
S 65° W	N 5° E	W	
S 35° W	N 30° E	SW	
SW	S 80° W	S 75° W	(Aoyama)
W	S 25° E	W	
SW	SE	S 60° E	N 10° E
S 60° W	W	S 65° W	N 60° E
S 60° E	S 50° W	NE	
W	S 80° W	N 65° W	
S 60° W	N 75° E	NW	
S 70° E	S 80° W	S 75° W	(Shiba)
S 65° E	N 60° E	S 55° E	
NW	S 85° W	NE	S 70° W
S 60° W	S 75° W	E	SW
W	N 15° W	S 80° W	SW
S 80° W	N 70° E	S 85° W	N 80° E
S 35° W	S 85° W	S 35° E	S 25° W
S 55° W	S 80° W	S 65° E	S 40° E
S 65° E	N 65° E	N 65° E	N 70° E
S 65° W	S 80° W	SE	N
W	E		S 80° W
N 75° W	N 70° W		N 35° E
S 80° W	N 85° W	(Hongo)	W
S 80° W	S 70° W		S 20° W
W	N 75° W	S 50° W	S 40° W
W	NE	N 50° E	N 85° W
W	N 70° E		N 35° E
S 80° W	S 55° E		N 10° W
S 65° W	S 70° W		N 70° W
S 65° W	N 70° W	(Shitaya)	N 80° E
W	NE		W
S 80° W	N 40° E	NE	S 75° W
S 75° W	N 80° E	S 50° W	S 50° W
S 75° W	S 50° W	NE	S

(b) 72 stone lanterns with stems of square section.

(Fukagawa.)

S		
S	30°	W
S	25°	W
N	35°	E
S	50°	W
S	30°	W
N	50°	E
W		
W		
W		
NE		
S		
W		
S	65°	W
S	75°	W
W		
W		
W		
E		
WSW		
W		
E		
W		
W		
W		
E		
S	30°	E
E		
SW		
S	70°	W
W		
S	75°	E
S	10°	E
E		
S	50°	W
S	75°	W
S	70°	W
N	80°	E
N	20°	E
N	80°	E
E		
N	55°	E
S	30°	E
S	70°	W
E		
W		
W		
N	70°	W
W		

(Hongo.)

W		
S	10°	W
N	10°	E
S	50°	W
N	80°	W
S	20°	W
S		
S	70°	W
S		

(Shitaya.)

N	20°	E
N	70°	W

(Shiba.)

SW		
N	30°	E
NE		
N	30°	E
N	25°	E
S	30°	W
N	40°	E
N	30°	E
N	40°	E
SW		
N	20°	E

(c) 21 miscellaneous cases, tops of stone lanterns, tomb-stones, etc.

(Fukagawa.)

NW		
NE		
S	50°	W
N	60°	W
N	70°	W
S	60°	W
W		
E		
W		
W		
W		
W		
S		

(Shiba).

SW		
S	35°	W
S	30°	W
N		
S	70°	E
N	40°	E

(Hongo.)

S	10°	W
N	70°	E

From table I, it will be seen that the majority of the columns were overturned towards WSW. Averaging all the directions of overturning, we obtain the mean value of N 71° E and S 71° W, which is exactly the direction of the maximum vibration as given by the seismograph diagram. Further it is to be noted that the cases of overturning exactly, or nearly, towards S 71° W were much more numerous than those towards the opposite direction. In this earthquake therefore the chief direction of the overturning was not contrary to, but the same as, that of the maximum displacement of the ground.

Uniformity of the overturning direction was likewise found to be the case in Mino-Owari earthquake of Oct. 28th 1891, and the Shonai earthquake of Oct. 20th 1894.

The result contained in table I (a) is graphically illustrated in fig. 2, in which each mark (×) indicates the overturning of one stone lantern in the corresponding radial direction. When several columns were overturned towards one and the same direction, an equal number of marks has been put along the proper radius.

The mean of the directions of projection of the tops of the ten chimneys in Tokyo broken by this earthquake * is nearly the same as that of the overturning, namely ENE and WSW.

8.—Specimens of the brick work of a few houses, chimneys and walls damaged by the earthquake were brought to the Engineering Laboratory and had their tensile strength determined. The results are given in table II.

* See § 25 of the present author's paper: Seismic experiments on the fracturing, etc.

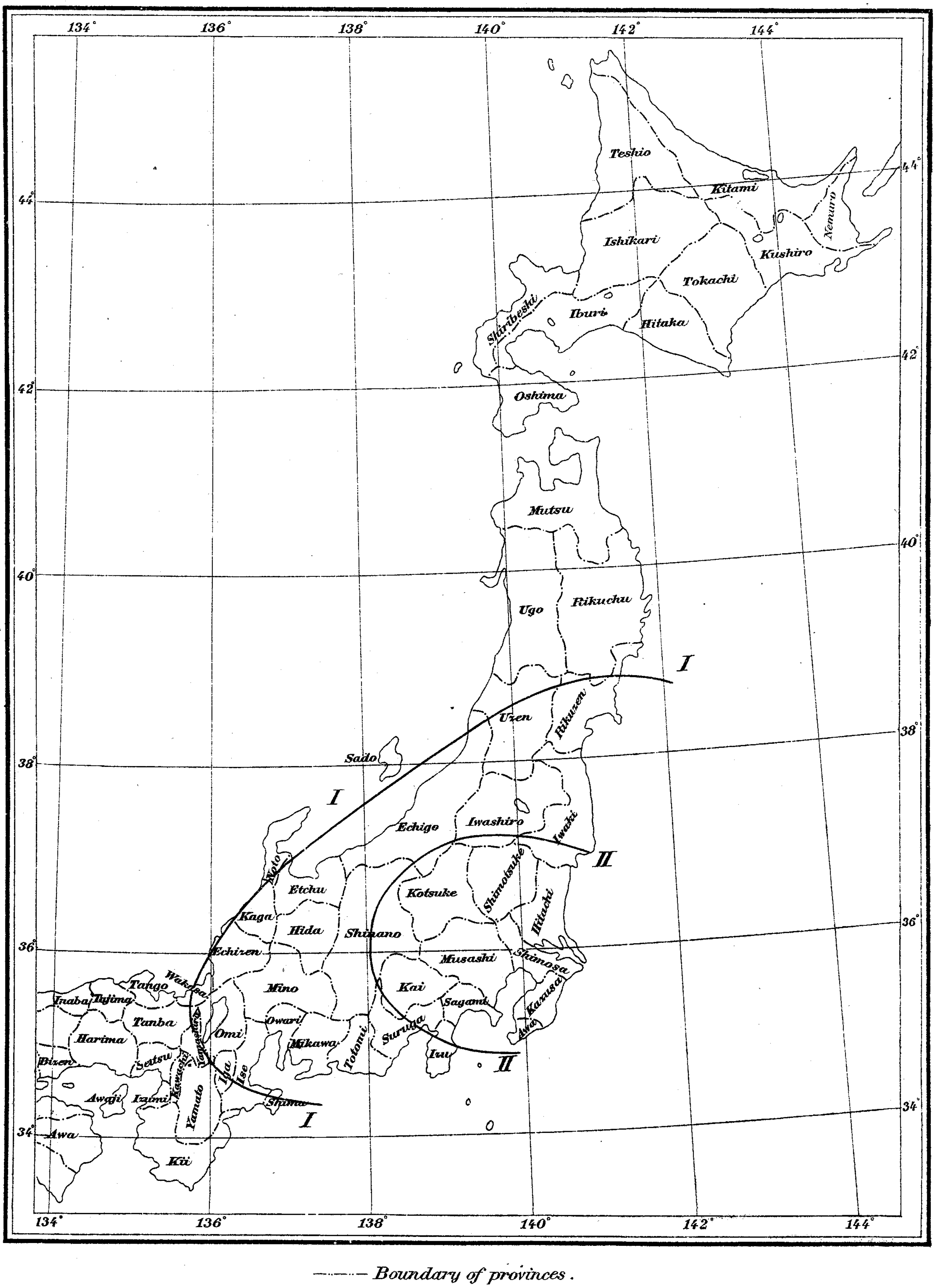
TABLE II.—TENSILE STRENGTH OF BRICK-WORK DAMAGED BY THE EARTHQUAKE OF JUNE 20TH 1894, IN TOKYO.

Building.	Quality of brick.	Thickness of the mortar joint.	Tensile strength per sq. in.	Composition of mortar.	Remarks.
Private dwelling house, Atagoshita, Shiba.	Ordinary 1st class.	$\frac{3}{8}$ inch.	lbs. 46.94	Lime and sand.	Broke through mortar.
	,,	$\frac{5}{16}$,,	16.52	,,	,,
			mean 31. 4		
Chimneys; Educational Department.	Extra-superior class.	$\frac{3}{8}$,,	22.76	Lime and sand.	Broke through mortar.
	,,	,, ,,	9.67	,,	Broke through mortar and brick.
	,,	,, ,,	11.15	,,	Broke partly through mortar and partly by separation of brick and mortar.
	,,	,, ,,	33.26	,,	,,
			mean 19. 5		
Wall; the Astronomical Observatory.	,,	$\frac{1}{4}$,,	87.72	Lime and sand.	Broke through brick.
Kinjō Gakkō.	Ord. 1st and 2nd class.	$\frac{9}{16}$,,	43.87	,,	Broke partly through mortar, and partly by separation of mortar and brick.
Rikkyō Gakkō.	Ordinary 1st class.	$\frac{3}{8}$,,	56.89	,,	Broke partly through brick, and partly by separation of brick and mortar.
Chimneys; the Okurashō.	Ordinary 2nd class.	$\frac{5}{16}$,,	22.89	,,	Broke through mortar.
Chimneys; the Naimushō.	Extra superior class.	$\frac{3}{8}$,,	48.72	Cement, lime and sand.	Broke partly through brick, and partly by separation of brick and mortar.
	,,	,, ,,	24.64	,,	Broke by separation of brick and mortar.
	,,	,, ,,	50.37	,,	,,
	,,	,, ,,	51.57	,,	Broke partly through brick, and partly by separation of brick and mortar.
			mean 43.8		
			General mean 44.0		

In the testing those cases of free separation of brick and mortar for which the tensile strength was nearly zero have been excluded. Hence the mean value of 44 lbs. per sq. in. is to be regarded as giving the average tensile strength of the better portions of the common brick-work.

Fig. 1.

The Earthquake of June 20th, 1894.



––·––·–– Boundary of provinces.
I, Boundary of the area of slight motion.
II, ... strong "

Fig. 2.

Diagram showing the directions of overturning of 152 stone lanterns, observed in Tokyo. (Earthquake of June 20th 1894.)