The Diagram of the Semi-destructive Earthquake of June 20th, 1894 (Tkōyō).

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(Pl. XXX.)

The earthquake of June 20th, 1894, was the most violent, that has shaken Tōkyō since the well-known great catastrophe of the 2nd year of Ansei (1855). The mean radius of the disturbed area was about 80 ri or 200 miles, and the total land area was 7,100 square ri, or 42,000 square miles. The meizoseismal tract was a zone lying to the east of Tōkyō, and extending in a N–S direction from the vicinity of the town of Iwatsuki to Tōkyō Bay. No house was absolutely destroyed, but in the lower parts of Tōkyō, many brick buildings received severe damage, and chimneys in particular were mostly thrown down; some *dozō* (godowns) had their plastered mud walls very much cracked and shaken down, tomb-stones and *ishidōrō* (stone lanterns in gardens) were overturned, small cracks were formed in the ground, and, in a few cases, ejection of water took place. The number of casualties in the three Prefectures of Tōkyō, Kanagawa, and Saitama were 26 persons killed and 171 wounded. In fact it was the severest shock that the younger generation has felt in this metropolis.

The diagram of the earthquake (Pl. XXX.) was taken by a Large Motion Seismograph, set up in the Seismological Institute of

the University, which was specially designed for recording strong earthquakes. The instrument is in principle the same as those often described in the papers in the earlier numbers of this Journal treating of seismological subjects. The main differences are, (*a*) the working parts are made stouter to withstand severe shakings, (*b*) the writing pointers are made longer so as to record large ranges of motion, and (*c*) the pointers have no multiplication ratio so that the actual magnitude of the motion is given. This is the first time that a clear instrumental record of a destructive earthquake was ever taken in this country : probably no such has ever been obtained in any other country.

The Seismograph records the motion decomposed into three components. The wave lines on the two inner circles indicate one the NE–SW, and the other the SE–NW components, and that on the outermost circle the vertical component. By compounding the component motions we can find the resultant. The recording plate revolved once in 118 seconds, and the short radial lines mark successive seconds of time counted from the start. We can thus determine the magnitude and direction of motion at any instant during the earthquake, as well as the duration, the intensity, and other elements of the shock. Below we give results deduced from the diagram.

Time of Occurrence. 1894, June 20th, $2^h 4^m 10^s$ p.m.

Horizontal Motion. The earthquake began as usual with tremors. The duration of tremors, as indicated by ordinary seismographs, lasted about 10 seconds. The Large Motion Seismograph does not record minute tremors, and the motion was already a few millimetres in range at the beginning of this diagram. However, we shall take this latter point as the beginning of the earthquake. The motion, already strong in the 1st and 2nd seconds, became suddenly violent and the ground moved 37 mm. during the time interval between the 3rd

and 4th seconds. This was followed by a counter-movement of 73 mm., which was the maximum horizontal motion during the earthquake, and was again followed by a motion of 42 mm. The motion during about 1 minute succeeding the above three most prominent shocks was very much weaker, though still great in range. Some large undulations occurred between the 40th and 53rd seconds and again between the 70th and 78th seconds. But the intensity of motion was not so strong as before. The comparatively little damage occasioned by the present earthquake notwithstanding such great horizontal movements is no doubt due to the small number of violent oscillations.

Period of Horizontal Motion. The above maximum horizontal motion was executed in 0·9 second, so that the complete period of oscillation would be 1·8 second.

Direction of Motion. The direction of the motion changed as usual during the earthquake. But the maximum horizontal motion was directed toward S. 70° W., and the chief movements before and after were also directed nearly towards the same point, or else the opposite direction. We have also examined the directions of overturning of 245 stone-lanterns (*ishidōrō*) in different parts of Tōkyō. Their mean direction of overturning was toward S. 71° W. Thus the direction of overturning of columns is seen to be identical with that of the maximum horizontal motion.

Vertical Motion. The maximum vertical motion of 10 mm. occurred in the 3rd second nearly simultaneously with the first prominent horizontal motion. Vertical motions occurred more or less during the next 30 seconds.

Maximum Acceleration. The maximum acceleration of the motion of an earth particle, calculated from the above values of the maximum horizontal motion and its period, is 444 mm. per sec. per sec.

This was the maximum acceleration in the upper districts of Tōkyō where the ground is composed of hard loamy soil; in the lower districts, where the ground is soft and marshy, it nearly reached the value of 1,000 mm. per sec. per sec. This latter has been calculated from a similar record given by another Large Motion Seismograph set up in the lower part of the city. Now the maximum acceleration is the quantity which measures the destructive power of earthquake motion, and it may therefore be inferred that whenever it reaches the above values, chimneys will be greatly damaged and buildings affected as on this occasion. For the Mino-Owari Great Earthquake of 1891, one of us has calculated, from observations of numerous overturned and fractured bodies, the maximum acceleration of earthquake motion in the meizoseismal district to have been from 3,000 mm. up to nearly 10,000 mm. per sec. per sec.[1] These results are probably the first numerical estimation that has been made of the destructive power of great earthquakes.

Duration of the Earthquake. The shaking lasted about 4 minutes and 30 seconds.

1. See F. Ōmori: *Table of the overturning acceleration*, etc. Seismological Jour. Japan, Vol. I, p. 143.

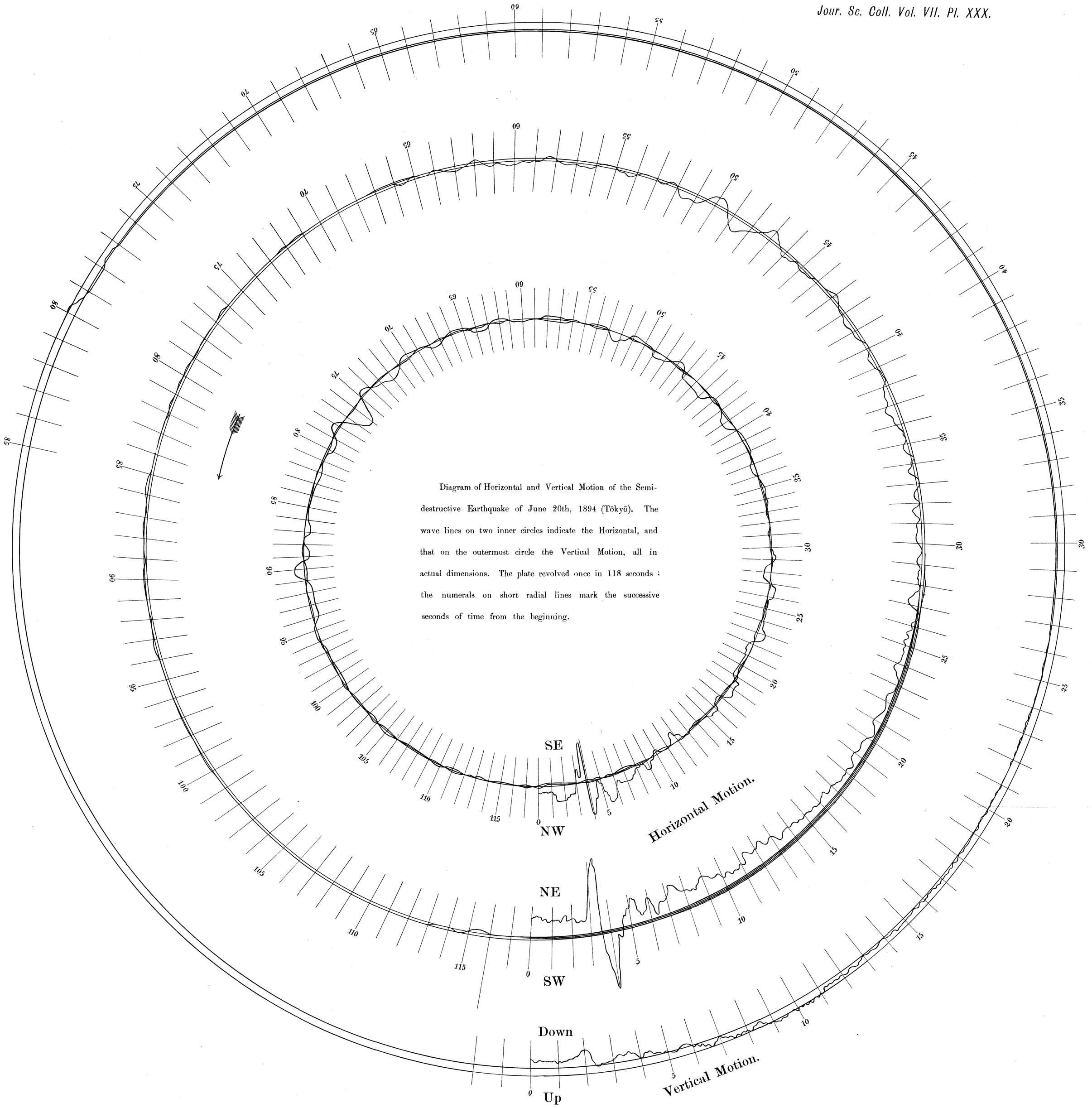

Diagram of Horizontal and Vertical Motion of the Semi-destructive Earthquake of June 20th, 1894 (Tōkyō). The wave lines on two inner circles indicate the Horizontal, and that on the outermost circle the Vertical Motion, all in actual dimensions. The plate revolved once in 118 seconds; the numerals on short radial lines mark the successive seconds of time from the beginning.