Comparison of Earthquake Diagrams simultaneously obtained at the Same Station by two Instruments involving the Same Principle, and thereby proving the Trust-worthiness of these Instruments.

By

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With Plates VIII.—XI.

In 1883, Prof. J. A. Ewing contributed a valuable, and now well-known, work on Earthquake Measurement to the memoirs published by this University, in which he described the theory and construction of seismographs of his own invention together with earthquake diagrams that were obtained by the use of these instruments. These diagrams have given many new and important results, and in several cases settled, in a decisive manner, questions relating to the character of earthquake motions.

This short paper is intended to treat of the further examination of similar diagrams recently obtained, and to prove the trust-worthiness of Horizontal Pendulum Seismographs. This is done by comparing the two diagrams of the same earthquake simultaneously registered by two instruments placed side by side in the Observatory. With this object in view two pairs of earthquake diagrams are given, which were originally photographed from the smoked glass plates on which they were recorded.

It is the writer's intention to give, in the next number of this Journal, the general results of observations especially relating to Vertical Motion and therefore the record of that motion is here studied, as a preliminary, in conjunction with horizontal movement. It is only by compounding the vertical and horizontal motions that we can obtain the complete tracing of the motion of the earth particles during an earthquake.

PLATE VIII. AND PLATE IX.

The Earthquake of May 18th, 1886.—This earthquake disturbed the plain of Musashi and its neighbouring provinces including a radius of 85 miles around; the origin of disturbance was inland 32 miles N.N.W. from the Observatory. It did scarcely any damage to buildings.

Instruments.—The record of the earthquake is shown by Plate VIII, which was taken by Prof. J. A. Ewing's Horizontal Pendulum Seismograph; the waves on the inner circle were traced by a pointer which registered north to south components of motion, and those on the outer circle by another which registered east to west motion. The pointers tracing these components are prolongations of horizontal pendulums, which magnify the motion of the ground four times, and produce their records on a revolving glass plate which is started by means of an electric contact maker. The plate is driven by a clock-work train, which, after starting, quickly reaches a steady rate under the control of a friction governor. The speed of rotation was one revolution in 80 seconds; the short radial lines mark seconds, so that the successive movement of the earth may be studied in conjunction with time.

Plate IX. which is the record of the same earthquake as that of Plate VIII. has the record of both horizontal and vertical motions;

the former was given by Horizontal Pendulum Seismograph of somewhat modified form, but similar in principle to the first. The horizontal motion of the ground was magnified nearly six times in this instrument, and a larger smoked glass plate of slower rate was employed. It is to be observed that the driving clock did not move at a perfectly uniform rate, but was slighly retarded towards the end. The circles are divided up to the eightieth second so as to facilitate the comparison of the two diagrams.

The vertical motion, which is given on the outermost of the three circles, was registered by Ewing's Vertical-Motion Seismograph; it has, for its astatic mass, a heavy bob suspended from a horizontal axis with an automatically changeable leverage. The magnifying ratio of this instrument is 1 to 8, or the motion of ground is magnified eight times on the record; the outside of the circle corresponds to up-motion and inside to down-motion of the ground.

Horizontal Motion.—In order to compare the two records of the horizontal motion, Plates VIII and IX. may be examined conjointly. It will be observed that the plates revolved in opposite directions as indicated by the directions of the arrows.

The records begin at *O*, but they are quite feeble till the end of the fifth second; then both the North-South and the East-West components suddenly exhibited vigorous movements; allowing for multiplication introduced by the recording levers (1 to 4 in Plate VIII. and 1 to 6 in Plate IX.) the displacement on the earth surface at the sixth second was 1.4 mm. from South to North and 0.9 mm. from East to West. When these two components are compounded together, they give a resultant of 1.8 mm. in the direction of N. 33° W. and S. 33° E. The complete period at this point is approximately 0.8 seconds.

Later on there are constant changes of phase relations in the waves of the both components, *i. e.*, waves in one circle are sometimes in advance of those in the other circle or *vice versâ*. This means that the particles of the earth moved more or less in a curvilinear path. At the twenty-third second there is a large East-West movement which has nothing to correspond with the North-South components. On the contrary, from the thirty-third second a series of vigorous undulations appear on the North-South components, while that of the East-West is still at rest; however at the thirty-sixth second, the latter suddenly takes up its motion along with the former. The measurements made at this point give a motion of 2.1 mm. in the direction of N. 47° E. and S. 47° W. with a complete period of 0.8 seconds, which is the maximum horizontal motion registered in this shock.

On these points readers are reminded to compare Plates VIII. and IX. and they will not fail to discover a close agreement between them.

During the interval of 80 seconds 91 complete waves may be counted, which makes the average period of one complete wave equal to 0.9 seconds. The undulations may be traced over one complete revolution of Plate IX. making the duration 2 minutes 24 seconds.

Vertical Motion.—The vertical motion begins at *O*, but up to the end of the sixth second it is nothing more than a series of very minute tremours recurring from four to six times in a second. At the sixth second when there is a large horizontal displacement, a vertical motion of only 0.2 mm. is registered; at the seventh second it is 0.4 mm. with a complete period of nearly 0.5 seconds, and is the maximum vertical displacement in this shock; then the motion continues with comparatively large amplitude till the end of the fourteenth second. The vertical motion may be traced up to the forty-fourth second, but the subsequent disturbance is entirely in the horizontal plane.

The horizontal and vertical motions thus measured may be compounded together so as to make the complete tracing of the motionpath of the earth-particles, which is then by referred to three rectangular co-ordinate axes. By introducing the vertical component to the already complex character of horizontal motion, we make the result still more complex. Without going into details it will be observed that at the seventh second while the ground was moving nearly 1 mm. in ES., it oscillated first 0.15 mm. downward and then 0.4 mm. upward. In this and other parts of the principal disturbance the period of vertical motion is less than one-half of that of horizontal movement, or in other words for one to-and-fro oscillation of the soil there are more than two simultaneous up-and-down strokes.

The ratio of the maximum vertical to the maximum horizontal motion is 1 to 5.3 for amplitude, and 1 to 3.3 for duration of disturbance.

PLATE X. AND PLATE XI.

Earthquake of December 19th, 1885.—This was quite a severe and extensive shock, shaking the country within a radius of 160 miles from its centre of disturbance, which was in the flattest part of Musashi Plain, near the sea and 37 miles E. 35° N. from the Observatory. The latter was in the midst of the affected portion of the country. No damage was done by this shock.

Instruments.—Plates X., and XI. which are the records of the above earthquake, are the exact repetition of Plates VIII. and IX. respectively. The same instruments were used in both cases under the same circumstances, except that the smaller plate was turned in the opposite directions at the rate of 84 seconds to complete one revolution, and the outer side of the East-West circle was made to correspond to West and the inner side to East.

The later and feebler parts of the record are cut out from Plate XI. in order to reduce the side of the plate.

Horizontal Motion.—The records begin at *O* and from the fifth to sixth second there suddenly appears one large undulation with the period of 1.7 seconds in the East-West circle with comparatively short-period waves on the other, and hence when these two are compounded together it appears that the ground moved approximately 1.1 mm. 55° W. and then 1.7 mm. N. 30° W. within the interval of 1.7 seconds. This is the largest horizontal motion in this shock. The record on the smaller plate may be traced over one and one-quarter revolution of the plate, corresponding to 106 seconds of time.

Vertical-Motion.—This begins at *O*, and up to the end of the seventh second there only but minute tremours of from .03 mm. to .09 mm. with a period of nearly 0.25 seconds. At the sixth second when the largest horizontal displacement appears the vertical motion is almost nothing, or at this point the soil still moved purely in a horizontal plane. From the tenth to the fourteenth second, a series of 8 distinct shocks of nearly equal amplitude is recorded, giving an average period 0.5 seconds. The greatest motion is 0.22 mm. at the eleventh second. The vertical motion may be traced up to the forty-third second with occasional rests between.

If we combine the three components exhibited on the diagram at the tenth second we will discover that, at this point, the ground was describing a loop or an elliptical figure whose major axis (pointing East and West) is 1 mm. and whose minor axis 0.4 mm. if we look from above downward, but at the same time the particles of the earth were actually performing two double oscillations of 0.2 mm. in the vertical plane. In the next second the motion was more nearly East and West with the usual rapid vertical oscillation. The composition of the three components may be carried out further in similar ways, but always leading to the same result which shows that the particles of the earth move in space in a most irregular and complex manner, and to try to picture the path pursued at the time of an earthquake is almost a hopeless task.

The ratio of the principal vertical to the horizontal movement ranges from 1 to 7 to 1 to 3 for amplitude, 1 to 2 for average period, and 1 to 2.4 for duration of disturbance.

Conclusions regarding the agreement of two diagrams of Horizontal Motion given by the same earthquake.

The object of the present paper is not so much to discuss the character of earthquake motion as to examine the agreement of two diagrams of the same earthquake taken by two Horizontal Pendulum Seismographs. If we go right through the records, wave by wave, or by means of the successive short radial lines, we will notice (taking into account the multiplying ratio of Plates VIII. and X. to be four and that of IX. and XI. to be nearly six) that the corresponding pointers in the two seismographs produced waves of exactly the same amplitude and period, both marking even irregular minor ripples between the principal undulations. These coincidences are faithfully repeated through all changes of amplitudes and periods to the end of the disturbance.

Such coincidence means either of two things,—(1) the steady mass in the instrument which serves as a datum line for registering earthquake motion remained stationary; or (2) the said mass in each instrument was moved exactly in the same manner during the prolonged shaking, and produced exactly the same error throughout. But what is called the steady mass is a hanging bob suspended by a horizontal lever, and therefore is free to oscillate round the axis of support with its own period of five to six seconds, or in other words, the bob is sensibly stable. If it had been at all affected by the continuous shaking of the earth it must have ultimately swung with its own period of oscillation; however it did *not* swing, as is clearly proved on the diagram by the shortness of the periods of undulation.

To find out experimentally the steadiness of horizontal pendulums, Prof. Ewing placed two of them on a shaky table, and by rigidly fixing the bob of one instrument to a neighbouring wall by means of a bracket, and letting the other bob free, he moved the table in such a manner as would resemble the earthquake motion. The free and fixed instruments produced waves which were almost alike to each other. This shows that the steady mass of the free pendulum remained stationary during the whole of the varied motion.

Allowing then for certain instrumental errors which cannot in all cases be eliminated, we have, in the agreement of records produced by similar instruments during the same earthquake, or during artificial shaking, evidence which conclusively proves the accuracy and trustworthiness of the Horizontal Pendulum Seismograph.

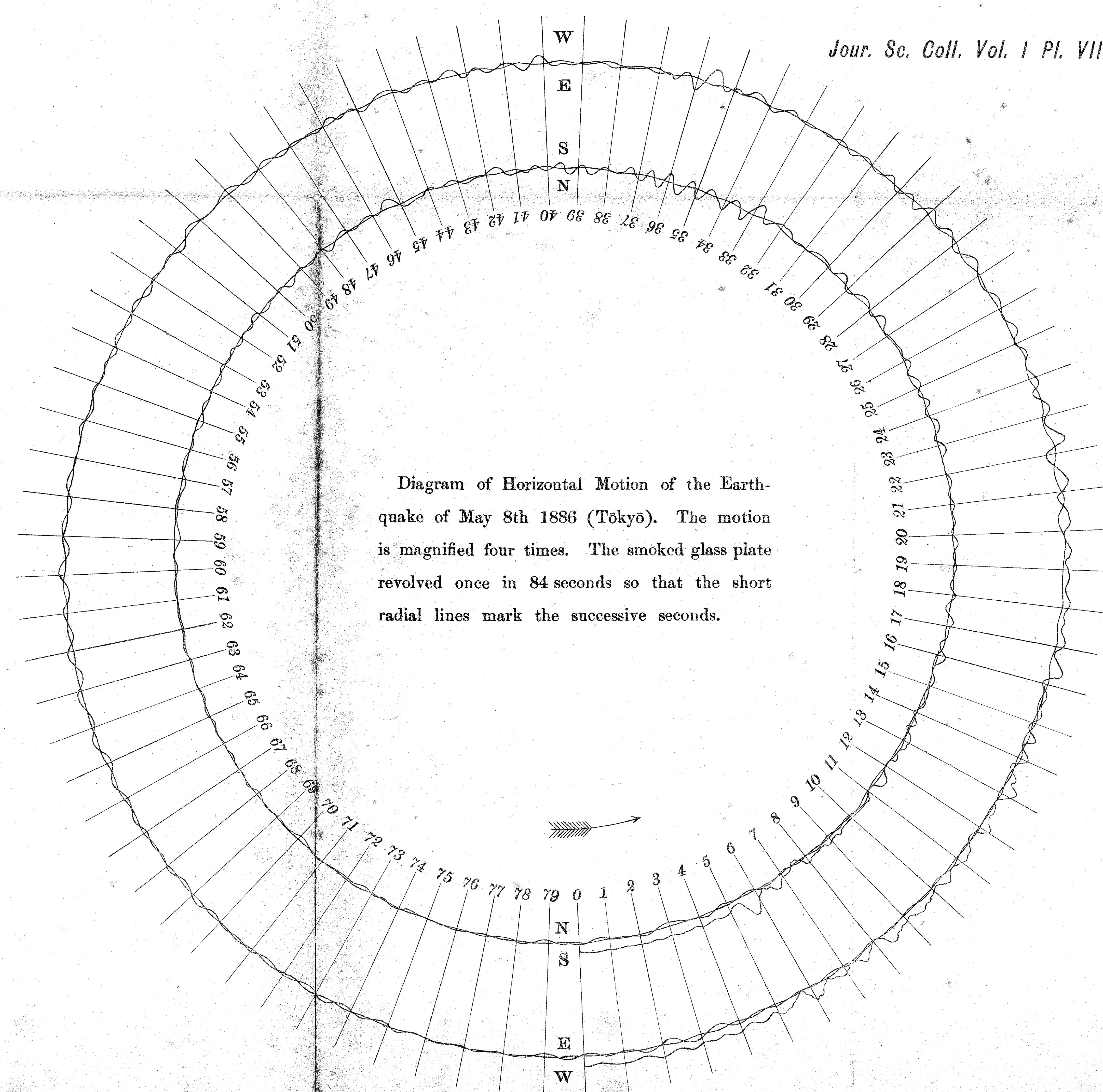

Diagram of Horizontal Motion of the Earthquake of May 8th 1886 (Tōkyō). The motion is magnified four times. The smoked glass plate revolved once in 84 seconds so that the short radial lines mark the successive seconds.

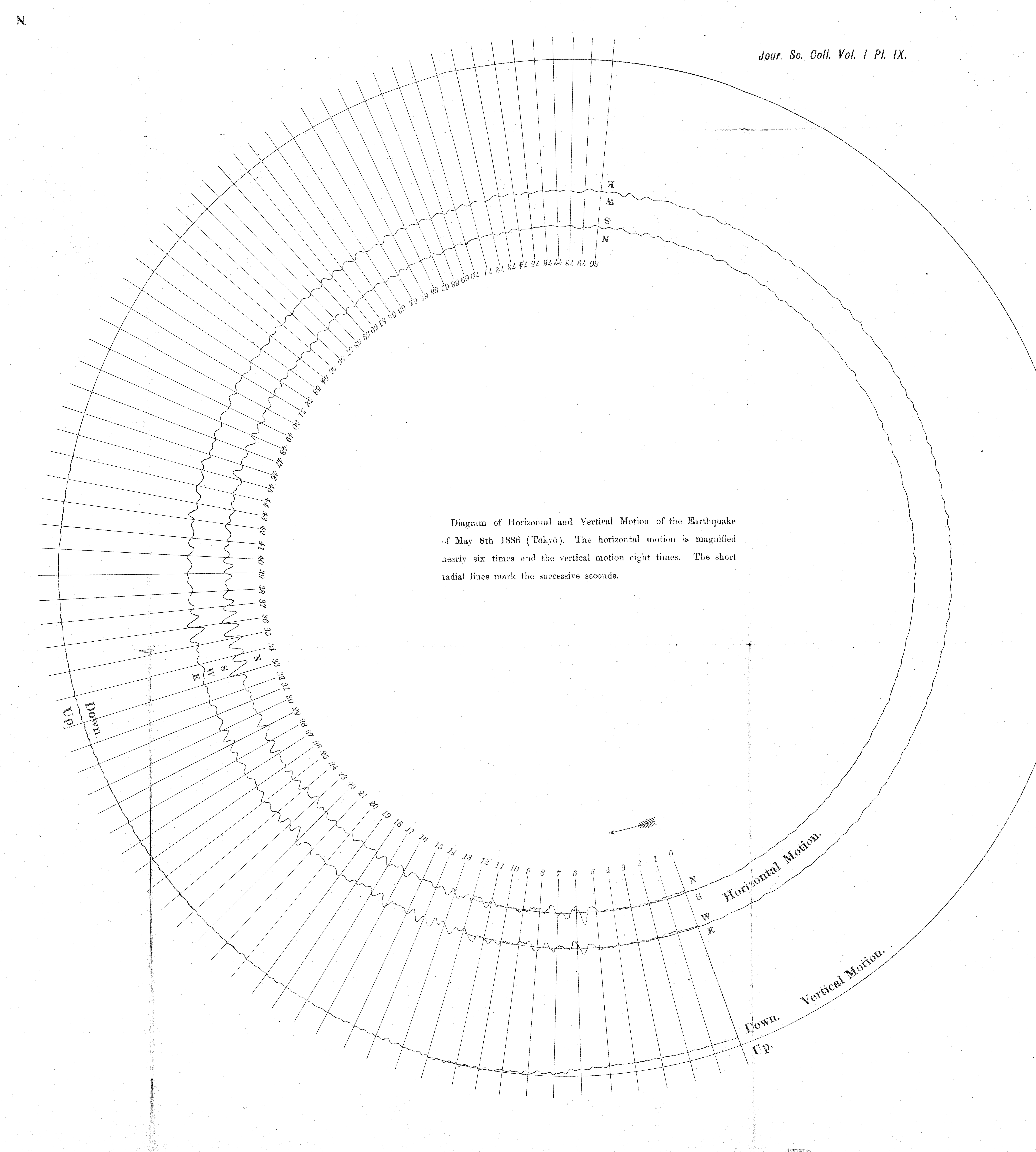

Diagram of Horizontal and Vertical Motion of the Earthquake of May 8th 1886 (Tōkyō). The horizontal motion is magnified nearly six times and the vertical motion eight times. The short radial lines mark the successive seconds.

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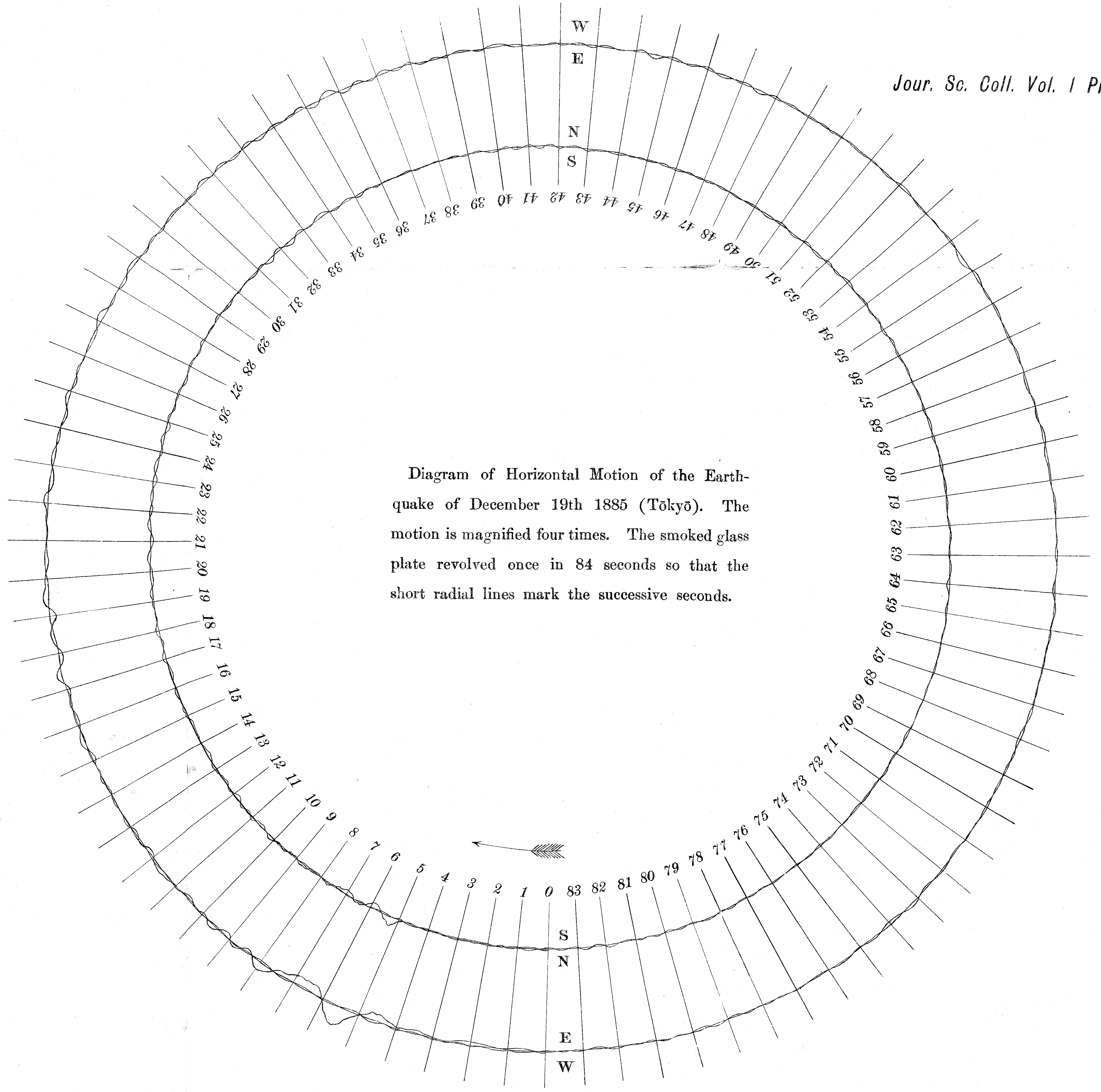

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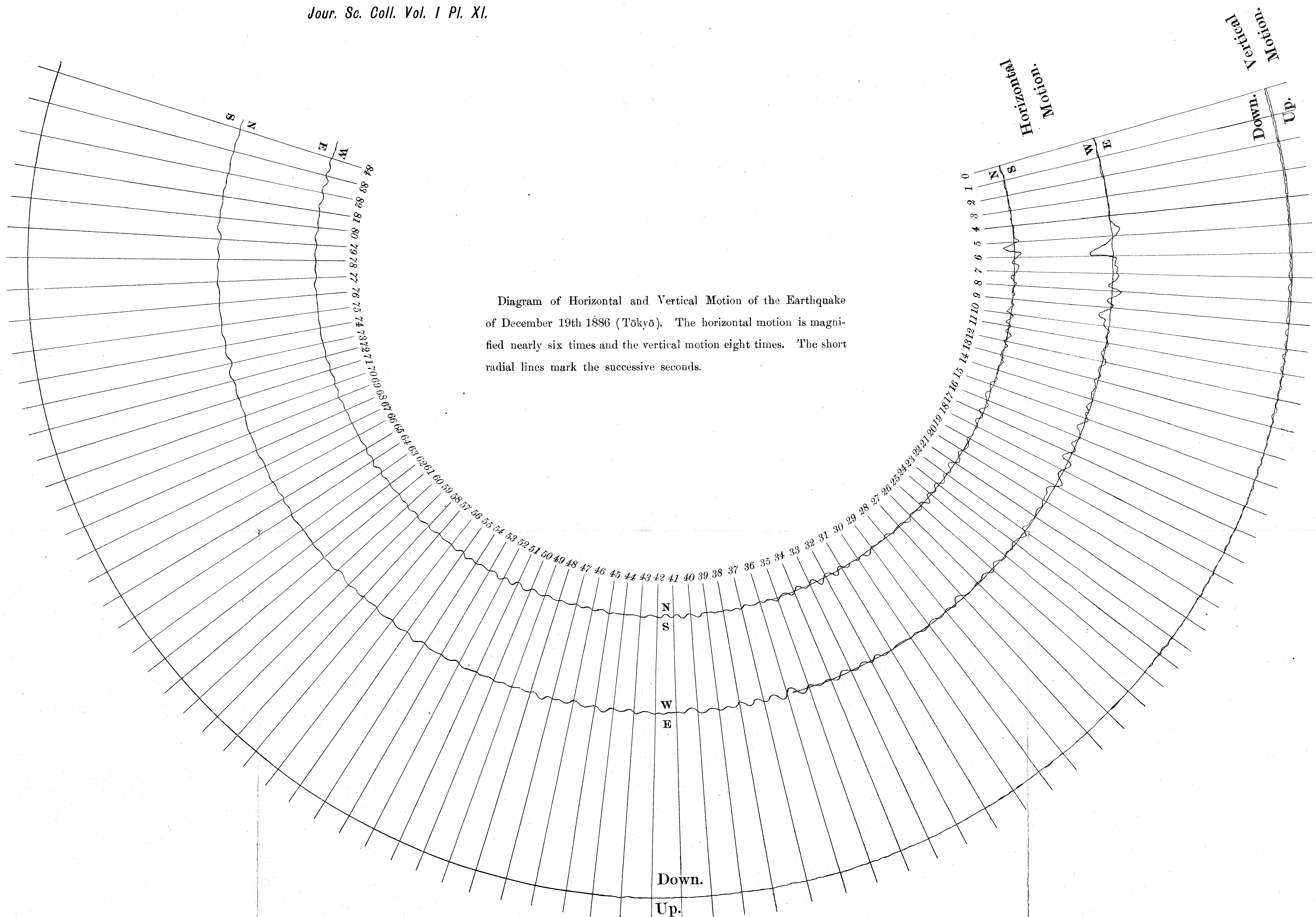

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