THE EARTHQUAKE OF MARCH 8th 1881.

BY

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At twenty minutes past noon on the 8th of March an earthquake occurred in Tokio, which, compared with the minute shakings we are accustomed to, was felt to be unusually violent and prolonged, although it did not (so far as I am aware) do any considerable damage to buildings. This impression was fully confirmed by a very clear record of the motion which was obtained by help of the "Astatic Horizontal Lever Seismograph" described before this society on the 22nd of December last.* As the record in question is by far the most valuable that has been given up to the present time, by this (and I believe I may add, by any other) instrument, and as it presents features which are displayed much more clearly in this than in earlier observations, I have thought it worth while to exhibit to the society photographs taken from the glass plate on which the record was traced, and to accompany them by a short notice of their chief points of interest.

The seismograph stands in the Engineering Laboratory of the University, in a part of Tokio well away from any elevated ground.

The record gives two components of the horizontal motion of the ground, magnified six times. Of these one is approximately North and South, and the other East and West. They

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* *See also Proc. R. S. Lond., No. 210, Feb. 10th 1881.*

are traced out by two pointers which mark their displacements radially on the suface of a smoked-glass plate which revolves under them continuously and uniformly. The record therefore consists of two undulating curves which represent the relation of the earth's displacement to the time in two horizontal directions at right angles to each other.

On the present occasion I was fortunate enough to be sufficiently near the seismograph when the motion began, to reach it in time to see the earthquake in the act of writing its record on the revolving plate. By that time the shaking had been going on for about a minute, and there were already a great number of waves traced on the plate by both pointers. The displacements were still considerable, and I was much struck to notice that the phase relation of the two components was continually changing. The motions of the pointers were such as could not possibly be due to earth waves of constant direction. While one pointer was moving vigorously the other was almost at rest, but a few seconds later the pointer formerly at rest had taken up the motion and the movement of the other had almost ceased. This alternation went on for some time, until, when the perceptible motion of the ground had nearly ceased, I removed the plate from the instrument to preserve the earlier portions of the record from being defaced by those which were then being traced above them. The plate was not taken out, however, until about two and a half minutes after the beginning of the earthquake. By that time each of the pointers had traced out a record containing nearly two hundred waves, and covering nearly two complete revolutions of the plate.

The earlier and more interesting part of the record is shown in the accompanying figure [lithographed from one of the photographs of the plate exhibited to the meeting]. There the circular path followed by the record round the plate has been cut up into four arcs, each of which corresponds to the same length of time, namely 20 seconds. These four arcs are consecutive. Each portion shows a *pair* of records: the upper one is the W. E. motion and the lower one the N. S. motion, and they are placed together so that the contemporary parts of these two curves lie on the same radius. The dotted radial lines divide the record into seconds of time, beginning with the point at which motion first became visible. Much care has been taken to verify by direct measurements from the glass plate itself the coincidence in time of those points in the two records which are here shown to be contemporaneous, since measurements made on the paper photographs were liable to error on account of the unequal contraction of different parts of the sheet in drying. It should be observed that the time intervals marked in the figure involve the assumption that the plate moved uniformly, which was approximately true. Any unsteadiness, however, in its motion would not in the least affect the relative positions of the two rectangular components of the record. The circular path which each pointer was tracing out previous to the earthquake is shown by a faint line.

The first sensible motion was a very slight one towards the west, but it was not until three seconds after this that the disturbance became at all considerable. A very decided movement took place at the fifth second, after which there was again less activity until the tenth. Up to that time the motion had been almost wholly confined to the W. E. directon: the other pointer showed scarcely a tremor. Near the tenth second however a large N.S. motion manifested itself, and during the remainder of the earthquake both components remained present, but in exceedingly variable proportions.

Perhaps the most interesting feature of this record is the varying relation of the W.E. and N.S. motions during the disturbance. From the tenth to the thirteenth second there appears to be synchronism between the two: during that time the displacements towards the East and towards the South were contemporaneous. But if we look at the record a little further on—in the neighborhood of the thirtieth second we find an equally distinct *opposition* of these two constituents of the motion: then, motions East and North coincide. In general, in other parts of the record, it is impossible to trace any distinct relation between the two components. For example, at the twenty-seventh second there is a notable movement from West to East which is not associated with any contemporary movement in the other direction. The same remark applies to the forty-third second and to the seventy-sixth. On the other hand, in several places, and especially during the twenty-third second there is great activity in the N. S. direction without anything to correspond to it in the contemporary record of the other component.

Towards the end of the figure, and more particulary in that part of the record which is not reproduced here, the curves exhibit the peculiarity which, as has been already observed, was noticed by direct observation of the moving pointers, namely the quiescence of one during a period of activity of the other and *vice versa.*

During the 16th second the motion is perhaps more energetic than at any other part of the disturbance. Besides this, the phase-relation of the two components there is peculiarly interesting. The W. E. component is in advance of the other by as nearly as possible a quarter of a period, and hence when compounded they show the remarkable result that at this part of the motion the earth's surface moved round in an approximately circular (somewhat-spiral) path. The greatest diameter of this path is about 18 millimeters on the record, corresponding to 3 millimeters of actual motion, and the complete revolution occupied 1.2 seconds. The direction of rotation was N W S E. We frequently hear of the motion during an earthquake being "vorticose" or "circular", as opposed to oscillatory. Here we have direct evidence of the temporary existence of a motion of rotation, as the result of two apparently independent linear vibrations at right angles to each other.

Taking the motion at the time now under discussion as uniform circular motion with diameter 3 mm. and period 1.2 seconds, we find for the greatest velocity 8 millimeters per second nearly, and for the greatest acceleration 41 millimeters per second per second. It is interesting to notice that a standing column seismoscope if overthrown during this part of the disturbance might have fallen indifferently in any direction, and would therefore have been useless as an indicator of the direction of propagation of the earthquake.

An inspection of the figure, which gives in *fac-simile* the records during the first eighty seconds of the motion, will suffice without farther verbal description to show the main features of the earthquake. In the remainder of the record, which is not reproduced in the figure, the motions were of pretty much the same general character, with amplitude which diminished gradually, though irregularly, as the disturbance drew to a close.

The characteristics of the record which have now been noticed will be sufficiently accounted for if we suppose that there were two independent linear oscillations of the earth taking place in different directions, and both of an irregular character. These may have been the normal and transverse waves which are the general result of a disturbance in an elastic solid. The beginning of the record indicates that one of these had at least approximately the direction East-West. If we suppose this (from the fact of its being the first to arrive at the observing station) to be the normal wave of elastic vibration of the earth, we must regard the North-South component as the transverse wave. This would point to an origin bearing (roughly) either East or West of the observing station. Accepting this interpretation of the record, it is not easy, owing to the gradual beginning of the motion, to say how far in point of time of arrival the normal waves were in advance of the transverse waves.

Other explanations may however be offered to account for the changes of direction which were continually occurring in the resultant horizontal motion during the disturbance. It is by no means impossible that there may have been two or more earthquakes going on at the same, or nearly the same time, and sending vibrations to the observing station along different lines. For in a district liable, as this is, to frequent earthquakes, we may fairly assume that there are at most times states of critical equilibrium existing in places from which the shocks originate ; and when one earthquake occurs the disturbance which it produces throughout the district may serve to destroy the already critical equilibrium and so cause one or more other earthquakes in other places. A system of waves beginning to arrive from a second centre a little later than the first group, and in a different direction, would sufficiently account for the very complex motions which were observed in this instance during all except the first ten seconds of the disturbance.

We may even suppose that the origin of the earthquake was so far extended, not discontinuously, as to give rise to considerable differences in the azimuths of waves reaching the observing station from different points along the line or throughout the area originally convulsed. But this involves either a very extended line of convulsion, or an origin at no great distance from the observing station.

Another possible explanation, even if we restrict ourselves to a single centre of disturbance and a single group—say the normal group—of waves, may be sought in the curvature which a line of propagation may acquire by passage through a non-homogeneous medium. In this way we might have a simultaneous arrival along two or more lines of waves which come from the same source.

With no more than this single example before us, it would be rash to discuss the relative probability of these different methods of explaining those features of the record to which, on account of their novelty, I have specially directed attention. However we interpret these, they afford unquestionable evidence that the direction of motion of the earth's surface, far from being the single and definite thing which many of the older writings on seismology imply that it is, had in this case all possible values round a horizontal plane at various times during the disturbance. I am not aware that distinct evidence of this has been furnished by any earlier observations. We have recently learned that more than one of the ideas about the character of earthquake motion which have been accepted apparently without question are entirely false. To the exploded fallacies of seismology we may now add the notion of a constant or principal direction of oscillation, to observe which by means of standing cylinder seismoscopes and other devices so many fruitless attempts have been made.

Note added November 1881.

In an article by Mr. Thomas Gray, "On Recent Earthquake Investigations," which appeared in the "Chrysanthemum" magazine for May 1881, the following passage occurs:—

"Prof. Ewing has assumed in some of his recent publications that he obtained in a recent earthquake the first distinct evidence of the existence of transverse movement. In this however he is mistaken, as very distinct evidence of these motions was obtained by the present writer in direct records on stationary plates long before the occurrence of the earthquake referred to. One notable instance was the long continued earthquake which occurred on Dec. 23rd 1880, when a very distinct record was written on a smoked glass plate placed under the bob of a pendulum. This record showed two distinct sets of very elongated ellipses one having the major axis nearly north and south and the other nearly east and west. Records obtained on the three component machines devised by the present writer and used in different parts of the country by Prof. Milne have also shown evidence of the same thing, the directions given by the three pairs of components being in some cases very different."

Apart from the fact that the records spoken of by Mr. Gray had not (to my knowledge) been published and that no such claim as is here set up had been made, before the foregoing paper was communicated to the Seismological Society, there is it appears to me a misconception on Mr. Gray's part, as to the evidence they afford of transverse motion. The facts cited by Mr. Gray do of course prove that the relative motion of the ground and the so-called "steady" mass varied in direction during earthquakes. But unless a time-record of the successive motions be taken, so that we may distinguish between records which are part of the earthquake, and records which are due to the gradually acquired motion of the "steady" mass, no satisfactory conclusion can be drawn as to whether the motion of the ground changes its direction during the shock. No evidence furnished by records on stationary plates can possibly be conclusive on this point. If the suspended mass has different periods of oscillation in two horizontal directions (and what suspended mass with two degrees of freedom has not?) it will in general acquire a motion with a varying direction from even a purely linear displacement of the ground. The well-known fact that a hanging lamp or the scale-pan of a balance is found swinging elliptically after an earthquake does not prove that the motion of the ground has not been constant in direction. The conclusive evidence of change of direction furnished by my record of the earthquake of March 8th is of so different an order from any that had previously been, or could have been, afforded by records on stationary plates that I cannot find in the remarks of Mr. Gray any reason to alter the concluding sentences of the above paper.