ON THE OBSERVATION OF EARTHQUAKE WAVES AT GREAT DISTANCES FROM THE ORIGIN, WITH SPECIAL RELATION TO THE GREAT EARTHQUAKE OF KUMAMOTO, JULY 28TH, 1889.

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Since the year 1889 I have been engaged in the observation of horizontal pendulums of extreme sensitiveness for the sake of ascertaining the true and apparent motions of the plumb-line. These instruments were mounted in cellars at the Observatories of Potsdam and Wilhelmshaven, and the motions of the pendulum were registered continuously by the aid of photography, the paper moving through 11 millims. per hour.*

Apart from the principal object of these experiments, which work is a continuous record of the position of the plumbline, my attention was soon attracted by certain seismological phenomena. Many cases occurred, in which remarkable perturbations were registered, which could only have been caused by distant earthquakes.

The distance of the two stations only being about 370 kilom., I could not expect to distinctly notice differences of time epochs of corresponding phenomena. In consequence of the slow motion of the paper the readings of time from the

* For more details see: "Das Horizontalpendel und seine Anwendung fur Beobachtung des absoluten und relativen Richtungs anderungen der Lothlinie," Nova Acta der Kais. Leop. Carol. Academie. Band LX. No. 1. The arrangements were such that changes of 0."001 and less could easily be detected.

photographic sheets would be affected by errors of 3m., and perhaps more on such days when the intensity and distinctness of the recording points of light were less. Thus it was impossible to deduce from the combined results of the two stations the direction, east or west, from which the motion had travelled.

Owing to the uncertainty of most of the earthquake reports from countries where no organization such as exists in Japan I have only been able to identify a small number of the observed perturbations with distant phenomena with at least some degree of probability. Doubt in this respect must remain as long as there is only one station. If there are several near to each other and we find that a perturbation has been observed at all of them, this will tend to confirm the supposition concerning their origin. But if only a few such stations were placed all over the world, probably not a single case would be found in which it would be impossible to fix the place from where the disturbance originated.

During the winter 1890-1891, the observations were continued at Port Orotava, the well-known health resort on Teneriffe. It was at this place, that earth pulsations, consisting of long flat waves were noticed for the first time-with the exception of one earlier observation made at Potsdam in February, 1889. Perturbations of other kinds were frequent, but in most of the cases of less intensity, owing perhaps to the different character of the soil, which was rocky whilst it was sandy at Potsdam and marshy at Wilhelmshaven.

In 1892, I transferred one of my instruments to the hands of Prof. Kortazzi, at the Imperial Naval Observatory of Nicolaiew, whilst the other one was removed to Strassburg, where it has been working continuously since July 18th last. The distance between the two stations now being 1,813 kilom., whenever a perturbation was observed at both places,—which was nearly always the case when both instruments were in action—it has been possible to determine the direction east or

west from which the shock had arrived. It was also shown that the figures formed at the two places by the swinging of the pendulum were very much like each other, a fact, which is of course of the greatest importance for the identification of certain movements of a perturbation, because these often last for hours. (See a list of perturbations observed at Nicolaiew and Strassburg in No. 3152 of the *Astronomische Nachrichten*).

The fact of earthquake motion spreading over large areas of the earth's surface and being observed at distances of many thousands of kilometers has led me to believe, that a *strong* motion might possibly be observed twice, arriving the first time from the direction of its centre one way round the world and then arriving by travelling round the other side of the world. In several cases I have observed two perturbations of a similar character following each other at intervals of 2.3 hours, and it is one of these cases which I wish to bring before the reader, because it seems to me to have a decided connection with the great earthquake of Kumamoto on July 28th, 1889.

In *Nature*, vol. 40 (1889) I have given an account of a perturbation observed on April 17th, 1889, at both stations in Germany, which I believe to have been caused by the strong motion of the earthquake of April 19th, 2 p.m., observed at Tokio. (See Trans. Seis. Soc. Vol. XV.) The time of propagation in this case was found to be 64 3 mm., the distance 9,000 kilom. and the velocity of propagation 2.335 kilom. per second.

On July 28th, 1889, at about 2½h. and 6h. p.m., Greenwich M.T., two perturbations appear at both places, both of moderate size and duration and rather similar in character. The beginning of these was read off as carefully as possible, but owing to the indistinctness of the figures and the non-existence of well-marked phases, the readings may be affected by errors of several minutes. Excepting this, the agreement is perfect. Taking the means for both stations and the above value of velocity, a rough calculation shows that the shock ought to have taken place at about 11.45 p.m.

The agreement between this and the observed moment (11.40) p.m. induced me to make a closer examination of the case. Kumamoto is situated in about 32.8° N. lat. and 130.7° long. East. of Greenwich. The distance between this town and a place midway between Potsdam and Williamshaven. (+53.0° N. lat., 10.6° East. long) is 8,860 kilometers on the surface of the earth. The complement of this to the circumference of the earth is 31,140 kilom. The principal shock occurred at 11.40 p.m., Tokio M.T., which is the same as 2h. 20.9 m. Greenwich T. From the readings of the curves, means were deduced for the intermediate point, giving 3h. 28.2m. and 6h. 6.0m. for the moments of arrival of the primary and secondary wave. The velocities resulting from these numbers are 2,188 and 2,304 kilom. per second, but it is easy to see that a value of about 2.3 kilom. satisfies equally well the first observation. The times required for propagation are 67m. on the shorter and 225m. on the longer way.

Thus we see that the above hypothesis in this case agrees entirely with the observed phenomena. But we will have to depend on future observations to remove the last doubt about the possibility of earthquake movement being observable at enormous distances.

To conclude I may remark, that there is nothing in the curves, that might refer to the second shock, observed on August 3rd, 2h. 18m. a.m.