RECENT SEISMOLOGICAL INVESTIGATIONS

IN

JAPAN.

BY

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NOTE.

This paper was prepared with the purpose of being delivered as an address at the Congress of Arts and Science of the Louisiana Purchase Exposition at St. Louis and small number of copies was printed for private circulation. But I was prevented almost at the last moment by unavoidable circumstances from leaving Japan, and it has now been decided to publish it as one of the Publications of the E. I. C. in foreign languages.

There is one remark that I wish to make here in order to prevent any misconception that may possibly arise from statements in this paper. I have stated that we have, taking the whole of Japan, nearly 1400 earthquakes recorded yearly; in Tōkyō alone, there are about 50 sensible earthquakes in a year, that is, about once a week. Now it might be thought from this, that we in Tōkyō must be living in a state of constant feeling of insecurity, but this is of course far from being the case : of these 50, large number is very slight, so slight that they would not be noticed at all except by a special few ; I may say that only once or twice a year at most, do people in Tōkyō have occasion to feel even temporary and slight alarm, and yet Tōkyō is in the most disturbed region of Japan.

I have to express my warmest thanks to Prof. Omori who has most kindly assisted me in every way, from the first getting together of materials to the last correction of proofs, and also to Professors Tanakadate, Kotô and Nagaoka, of Science College, members of the E. I. C., for their valuable suggestions and criticism ; and to Dr. K. Nakamura, Director of the Central Meteorological Observatory, also a member of the E. I. C., for giving me informations on many points; likewise to Prof. Purvis of the Engineering College, who has looked over the paper and helped in seeing it through the press.

Aug. 31st, 1904.

D. Kikuchi.

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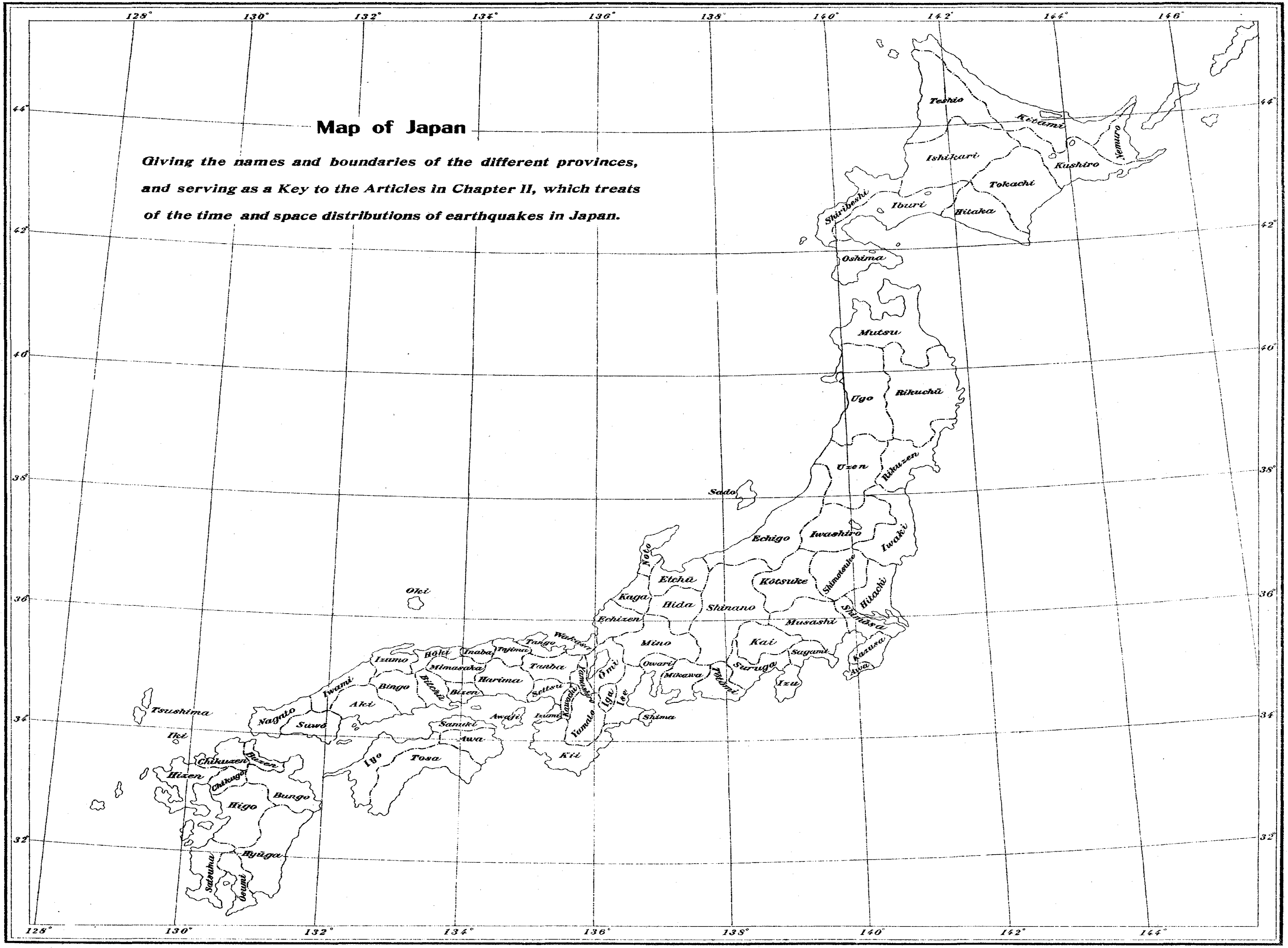

Map of Japan

Giving the names and boundaries of the different provinces, and serving as a Key to the Articles in Chapter II, which treats of the time and space distributions of earthquakes in Japan.

RECENT SEISMOLOGICAL INVESTIGATIONS IN JAPAN

CHAPTER I. INTRODUCTORY.

1. Japan is preëminently a land of Earthquakes. The number of earthquakes in the whole of Japan in the year 1903 was 1349, which is by no means above the average. Since 1872, 15 earthquakes have occurred sufficiently severe to cause loss of life or serious damage to property; it may be added that this number would have to be considerably increased, if we included such shocks as would have caused damage in Europe or America, where buildings are much higher than in Japan without precautions being taken against earthquake shakings.

2. The earthquakes come with such suddenness, their effects are often so terrible, there is something so mysterious about them, that they have attracted the attention and excited the wonder and terror of our countrymen from the earliest times. The first mention of an earthquake in the authentic history of our country is in the reign of Emperor Inkyō, A. D. 416, when the district of Kawachi was very severely shaken. Since then up to the year 1867, over 2000 earthquakes are recorded in history, of which some were very severe, causing considerable damage and loss of life.(1)

3. In 1854 (the year of the conclusion of the first treaty with

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1) A catalogue of these earthquakes in English is given in the Jour. Sc. Coll. (Journal of the College of Science, Tōkyō Imperial Univ.), Vol. XI., pp 315-435.

the United States), a gentleman in Tosa counted the number and measured the intensity of the after-shocks of the terrible earthquake of that year by observing oscillations of a swinging body. In 1855, an intelligent shopkeeper in Tōkyō is said to have noticed that some time before the great earthquake of that year, several nails previously attached to a loadstone in his shop dropped from it; a physician thereupon devised an instrument in which this supposed property of a magnet is utilized to give warning of a coming earthquake by ringing a bell.

It was quite natural, therefore, that when Western Science and scientific methods began to be introduced into Japan, they should be applied to the investigation of the seismic phenomena. Soon after the Restoration of 1868, the Government anxious to introduce Occidental civilization and knowledge into Japan invited Europeans and Americans to act as advisers to government departments, and instructors in the newly established schools and colleges, and it was mainly by these that the scientific study of earthquakes was first taken up. It would be a difficult and invidious task to try to give proper credit to each individual, but a special mention is due to Prof. Milne, who by his infectious enthusiasm and untiring energy has done more than any other to stimulate interest in, and to advance the systematic study of the phenomena. In Seismometry, the names of Prof. T. Gray and Prof. J. A. Ewing will stand forth most prominently. Among others to be mentioned are Rev. C. F. Verbeck, who made observations with pendulum and other devices as early as 1872; Dr. C. Wagener; Prof. W. S. Chaplin, who was the first to apply the horizontal pendulum, now so much employed in seismographs, to seismometry; Prof. C. D. West; and Prof. C. G. Knott. The founding of the Seismological Society of Japan in 1880 gave a great impetus to the study of earthquakes; 16 volumes of its Transactions,[1] the last issued in 1892, together with 4 volumes of the Seismological Journal of Japan, which may be regarded as a continuation of the same, contain some of the most valuable contributions to the advancement of Seismology.

4. In 1875, Palmieri's Seismometer[2] was set up in the Central Meteorological Observatory in Tōkyō, and its indications were reported in the papers. This instrument continued to be in use until 1883, when it was replaced by seismographs of the type usually known in Japan as Gray-Milne's. A modified and improved form of these seismographs, together with arrangements for indicating the time of the shock, is now in operation, not only at the Central Meteorological Observatory and the Seismological Institute of the Tōkyō Imperial University with its branch stations, but also at 71 local meteorological stations. [See Art. 45.]

5. It had come to be felt by the more advanced among us, not only that the study of earthquake phenomena was of great practical importance to us, but also that organised scientific investigation connected with seismology was a duty which Japan owed to the scientific world. On the practical side were considerations of houses built in foreign style, arches, bridges, chimneys, &c, new to Japan; these were designed and constructed without proper attention to the probable effects of the earthquake shocks peculiar to this country, shocks not occurring except very rarely, and therefore not being taken account of, in the countries from which these structures were introduced. On the other hand, perhaps no other

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1) Referred to subsequently in this paper as Trans. Seism. Soc.

2) A description of this instrument is given in the Encyclopaedia Britannica, 9th edition, Vol. VII, Art. "Earthquake."

country in the world offered such an opportunity for making a scientific study of the phenomena.

Thus, in 1886, when the University of Tōkyō was partially reorganised, a chair of Seismology was established in the College of Science, and Mr. S. Sekiya was appointed first professor of Seismology; he had previously to this taken up the subject as his specialty at my suggestion and had been in charge of a small seismological laboratory in the University, under the superintendence (at first) of Mr. J. A. Ewing, Prof. of Mechanical Engineering and of Physics. The chair has been occupied, since the lamented death of Prof. Sekiya, by Prof. F. Omori (who also took up this specialty at my suggestion). The chair is unique in the world. The Seismological Institute attached to the chair was removed last April to a little more commodious building than it had hitherto occupied.

6. In October, 1891, took place the great Mino-Owari Earthquake, felt throughout the whole of Central and Southern Japan, in which over 7000 people were killed, over 17,000 injured, and nearly 20,000 buildings destroyed, besides bridges, arches and miles of railways, embankments, &c. This earthquake, one of the severest ever felt, certainly the severest since the Ansei Earthquakes of 1854 and 1855, caused, as may be imagined, the profoundest impression throughout the whole country; a representation[1] to the government was proposed in Dec. 1891 in the House of Peers, then in its second session, by myself, supported by the principal members, and passed by a large majority, calling upon the government to take steps to establish a bureau or appoint a committee for studying earthquakes with a view to lessen their

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[1] See the E. I. C. Publ., No. 3.

disastrous effects. In accordance with this representation, a committee was organized by Imperial Ordinance dated June 25, 1892, entitled the *Shinsai Yobō Chōsakwai*, literally a Committee for investigating the prevention of earthquake disasters, more usually known as the Earthquake Investigation Committee. The object of the Committee is twofold:—in the first place to investigate whether there are any means of predicting earthquakes; and in the second place to investigate what can be done to reduce the disastrous effects of earthquake shocks to a minimum, by the choice of proper structures, materials, position, &c. The Committee has from the first taken a most liberal view of its functions and while always holding the above mentioned twofold object in view, has not hesitated to undertake any investigations within its means likely to tend to the attainment of this object, even such as are but indirectly connected with it, and would not have been necessary, had other bodies or individuals been doing the work (as would be the case in Europe or America). Its first president was Dr., now Baron, H. Katō, then the President of the Tōkyō Imperial University, with myself as secretary: on Dr. Katō's retirement next year, I became president and held the post until 1901, when I was succeeded by Prof. Tatsuno; the latter retired in 1903 and was succeeded by the present president, Prof. B. Mano. Prof. Ōmori, who has always been the most active member of the Committee, has held the secretaryship since 1897. Its present members are 24 in number, all scientific men or engineers. Its annual appropriation has been between 12 and 14 thousand dollars. It has so far published 47 numbers of reports in Japanese, and 16 in foreign languages, mostly English. [I give as an appendix a list of the contents of these reports, which will show what kind of work it has been doing.][1]

7. As the recent seismological investigations in Japan are almost wholly the work of this Committee in conjunction with the Seismological Institute of the Tōkyō University, what I am going to say will practically be an account of that work and its results.

The work may for convenience be classified as follows:—

1) *Statistical*: consisting chiefly of collecting of records and reports of earthquakes and "*tsunamis*"[2], descriptions of the effects of the shocks, &c. From these data are deduced the distribution of earthquakes (*a*) in time, and (*b*) in space; their relation to the seasons, the phases of the moon, the times of the day, and the meteorological conditions; parts of the country most shaken, maritime or inland, &c.

2) *Instrumental*: consisting of observations with seismometers and seismographs; investigations into the construction of instruments, the invention of new, and improvement and modification of old; "the Seismic Triangulation," &c. From these observations, are deduced the nature of the vibrations of earth particles, their amplitude and period, the velocity of earthquake waves, and so on. The observations of distant earthquakes also come under this head.

3) *Geological*: including reports of volcanic eruptions, dislocations, &c. Under this heading comes also the Vulcanological Survey, whose object is "to study the new and old volcanoes of

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1) In the subsequent part of this paper, the Committee will be referred to as the E. I. C., its reports in Japanese as the E. I. C. Hō (its full Japanese title being Shinsai Yobō Chōsakwai Hōkoku) and its publications in foreign languages as the E. I. C. Publ.

2) "Tsunami." This is the Japanese name for those destructive sea waves, which frequently devastate the coast of Japan. They have often been designated "tidal waves" or "seismic sea waves," but I have preferred to retain the original name.

our country as regards their internal structure, their rocks, their foundations and their modes of distribution,''[1] so as to be able to get ''an insight into the structure of the land;'' and ''to construct the geotectonic map, by means of which we could possibly know the condition underground, and the causes of the regional shaking and the local points of earthquakes.''

4) *Physical*: consisting of investigations of such physical phenomena, as it seems reasonable to suppose *a priori* have some relation with seismic phenomena, with a view to ascertain whether such a relation does really exist, and if so, what is its nature. Among these are Earth Magnetism, Variation of Latitude, Gravity, Underground Temperature, Seiches, Elasticity of Rocks, &c. These investigations, by establishing a relation between earthquakes and some phenomena which we can observe continuously, might help us towards the ultimate object of the E. I. C., viz, the earthquake prediction.

5) *Practical*: this forms a special feature of the work of the E. I. C., being one of the two ultimate objects, for which the Committee was organized. It comprises investigations of earthquake-proof structures, best forms for chimneys, piers, columns, &c.; the strength of materials and combinations of materials, and so on. The Committee has also extended its work to the application of seismometrical instruments to the measurement of vibrations of the ground, and of vibrations of buildings and structures, due to causes other than earthquakes, such as passing of trains over bridges, hammering in factories, and the like, and to an examination of their effects. Evidently, this investigation must to a very

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1) Prof. B. Kotō: The Scope of the Vulcanological Survey of Japan; the E. I. C. Publ., No. 3.

large extent depend upon the results of the work mentioned under the preceding heads.

CHAPTER II. STATISTICAL.

8. We have at present, besides the laboratory of the Seismological Institute of the Tōkyō Imp. Univ. and stations in direct telegraphic communication with it in Tōkyō and its suburbs, the Central Meteorological Observatory also in Tōkyō with full seismographic equipment, Kyōto Imp. Univ., 71 local meteorological stations provided with seismographs, and 1437 stations not provided with instruments, scattered throughout Japan. From all of these, reports of earthquakes observed or felt are sent to the Central Meteor. Obs. The 71 stations above-mentioned are in telegraphic communication with the nearest telegraph office and receive time daily direct from the Tōkyō Astronomical Observatory,—an arrangement initiated and maintained at the cost of the E. I. C.

9. The E. I. C. appointed Mr. Tayama to search for and examine the accounts of earthquakes recorded in history and in "the materials for history," under the superintendence of Prof. Sekiya, and after his death, of Prof. Ōmori. The result of his work is given in the two volumes forming No. 46 of the reports of the Committee, and entitled "The Materials for the Earthquake History of Japan;" in it are collected extracts from nearly five hundred books, pamphlets, reports, diaries, &c. relating to over two thousand earthquakes between the years 416 and 1867. Some of these give very full account of the damage caused, of various occurrences supposed to have been premonitory, of the state of the popular feeling at such times, and so on, so that they will be valuable not merely to seismologists, but to historians, sociologists, psychologists and others. This work owes much of its completeness to the courtesy of the Shiryō Hensan Gakari (Committee for the Compilation of Materials for the History of Japan) of the Tōkyō Imperial University, to whose collected materials Mr. Tayama was allowed free access at the request of the E. I. C.

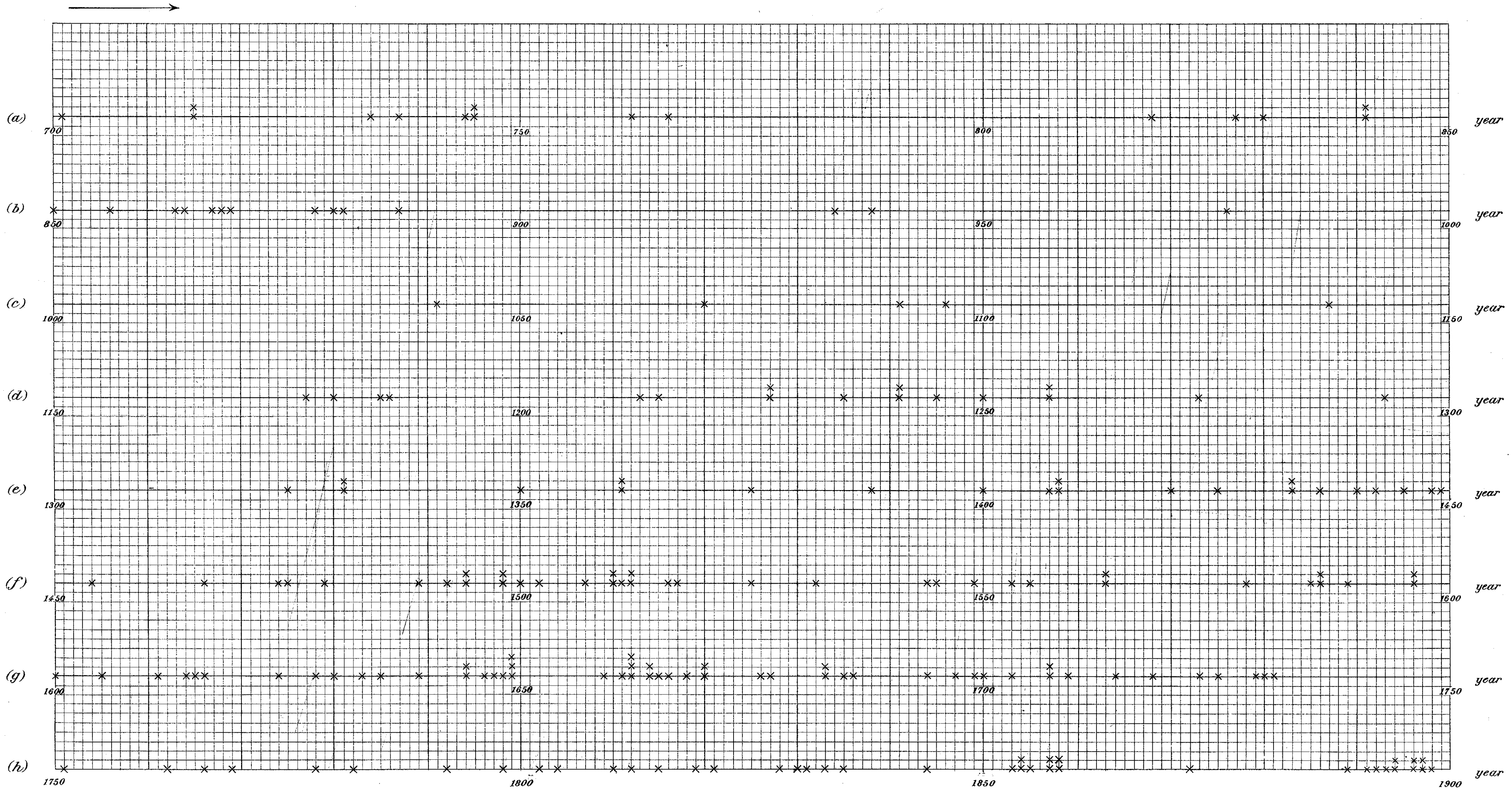
10. The E. I. C. has sent its members and others to the scenes of very strong earthquakes, of which there was an unusually large number in the nineties, beginning with the great Mino-Owari earthquake (Oct. 28, 1891); notably those of Noto (Dec. 9, '92), Kagoshima (Sept. 7, '93), Eastern Hokkaidō or Yezo (March 22, '94), Tōkyō and vicinity (June 20, '94), Shōnai (Oct. 22, '94), Ugo and Rikuchū (Aug. 31, '96), Nagano (Jan. 17, '97), Sendai and Eastern Rikuzen (Feb. 20, '97), besides the destructive "tsunami" along the north eastern coast on June 15, '96, and in addition several volcanic eruptions, landslips, subterranean noises, &c. The Committee has even sent members to foreign countries or asked the Japanese consuls and others to report on similar phenomena, for instance the Indian Earthquake of June 12, 1897. The Reports presented will be found in several numbers of the E. I. C. Hō.

From the materials obtained in the above ways, many important conclusions have been arrived at, both of theoretical interest and of practical importance: some of these I proceed to state below.

(A) Time Distribution of Earthquakes.

11. The earth's crust is under continual stress, and when the strain thereby produced reaches a certain limit, the stress must be relieved, generally by some sudden (geotectonic) convulsions, thus

FIG. 1. TIME DISTRIBUTION OF DESTRUCTIVE EARTHQUAKES IN JAPAN. (Formosa, Hokkaidō and Lyū-Kyū excepted.) From the 8th century to the present time.



Each sign (×) marks a destructive eqke; when two or more such shocks happened in a single year, the signs are put one over the other.
(*b*) is the continuation of (*a*),(*c*) that of (*b*), etc.

causing earthquakes. Among the forces acting on the earth's crust, there are external ones like the atmospheric pressure, the attraction of the moon, &c., having different periods. Hence, we may reasonably expect to find some such periods in the earthquake frequency: we shall see how far the result of observations fulfils this expectation.

Destructive earthquakes.

12. *The total number* of destructive earthquakes in Japan (Formosa excepted) during nearly 1500 years since 416 is 223. Confining our attention to the period of the Tokugawa Shōgunate and the Meiji era (i.e. from the commencement of the 17th century down to the present) during which the record of destructive earthquakes is, except for Hokkaidō and Lyū-Kyū, pretty perfect, we see that the mean interval between two successive destructive earthquakes has been, for the whole of Japan, about 2½ years. The number of years in which one or more destructive earthquakes occurred is 78 in the interval of 303 years since the beginning of the 17th century, the maximum in one year being 3. In other words, 26 years in every 100 were visited by from one to three destructive earthquakes, the other 74 remaining free from such seismic disturbances.

The distribution in time of the destructive earthquakes in Japan (Formosa, Lyū-Kyū, and Hokkaidō excepted) from the 8th century to the present is graphically shown in fig. 1, from which it will be seen that although shocks have sometimes happened singly or isolated, they have had a tendency to occur in groups. Thus 154 earthquakes since the beginning of the 14th century may be divided more or less definitely into 41 groups; the average value of the intervals between the mean epochs of the successive groups being 13⅓ years.¹⁾

13. *Annual Variation of the Frequency.* If we take the destructive earthquakes by the months in which they occurred, we have the maximum of 32 in August, and minimum of 10 in January: if by the seasons, the maximum of 74 in summer, and the minimum of 48 in winter. These results are illustrated in figs. 2 and 4.²⁾

Comparing figs. 2 and 4 with figs. 3 and 5, it will be seen that the annual variation of the frequency of the destructive earthquakes is just the reverse of that of the ordinary small shocks. To explain this fact, it may be remarked that if an earthquake implies the removal of an unstable point in the earth's crust, and the consequent settling of the latter to a stable condition, the constant occurrence of small earthquakes is to be regarded as maintaining the region concerned in a comparatively safe condition, by preventing any abnormal accumulation of stress in the earth's crust: their non-occurrence or an unusually low seismic frequency may, on the other hand, cause an accumulation of stress in the earth's crust, thereby facilitating the occurrence of great or destructive seismic disturbances.³⁾

Earthquakes at Kyōto.

14. Kyōto was the capital of the Empire during the 1070

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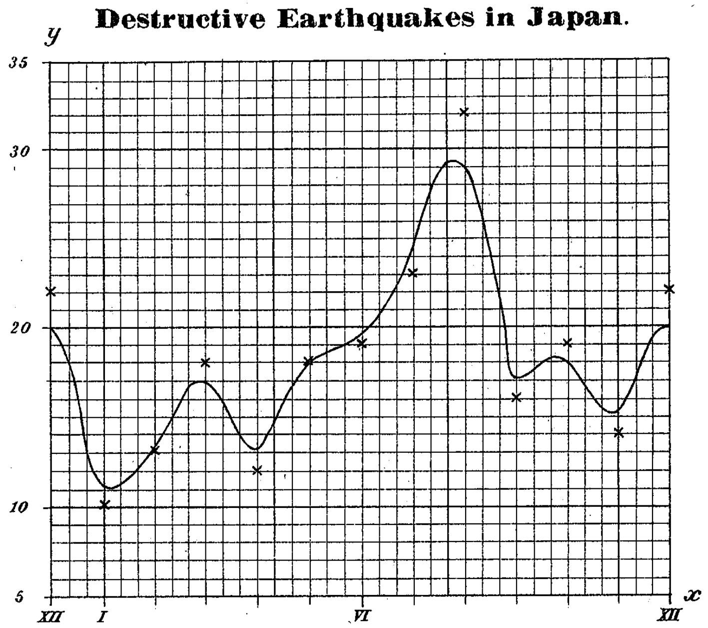
1) F. Omori: Notes on the E. I. C. Catalogue of Japanese Earthquakes. Jour. Sc. Coll., Vol. XI, pp. 411-413.

2) The curves are drawn, not always through representation points themselves, but by free hand through tho positions of the arithmetical means of every two successive points. This method of curve drawing has been employed in the cases of other similar figures.

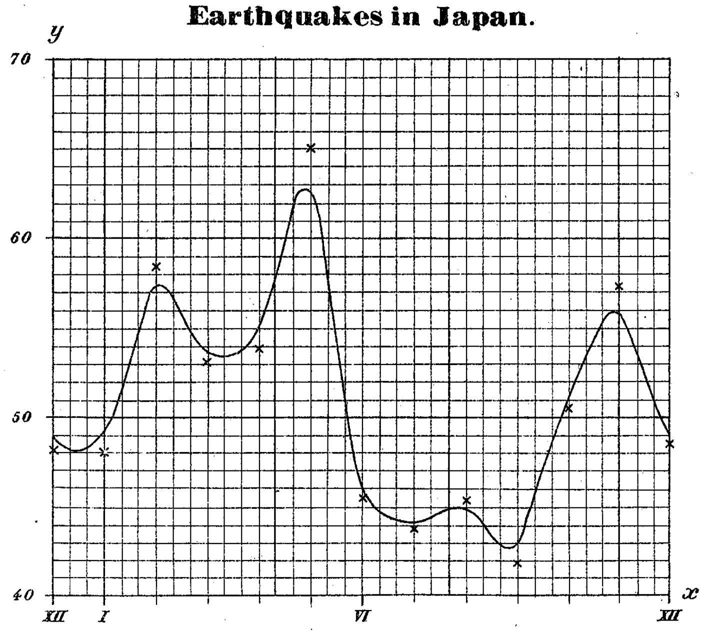
3) F. Omori: Notes on the E. I. C. Catalogue of Jap. Earthquakes. Jour. Sc. Coll., Vol. XI, pp. 403—408.

Fig. 2. Monthly Distribution of 216 Destructive Earthquakes in Japan.



x=Month.
y=Monthly number of destructive
eqkes.

Fig. 3. Monthly Distribution of Ordinary Earthquakes in Japan.



x=Month.
y=Mean monthly number of ordinary
eqkes.

Fig. 4. **Seasonal Distribution of 216 Destructive Earthquakes in Japan.**

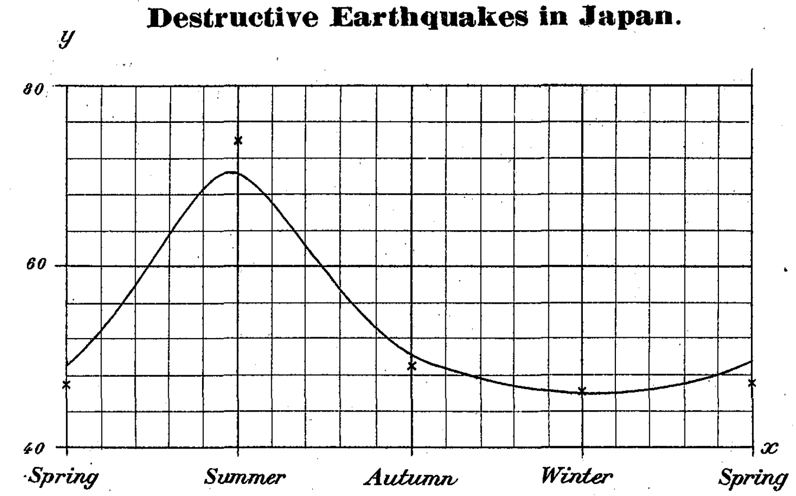
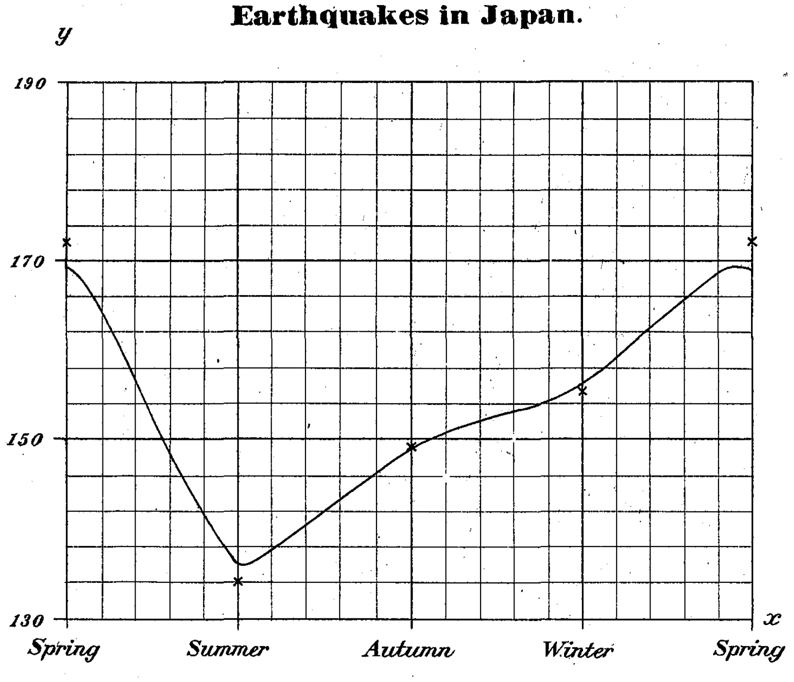


Fig. 5. **Seasonal Distribution of Ordinary Earthquakes in Japan.**



years between 797 and 1867. Being the centre of literary culture during this period, earthquakes in this city have been very carefully recorded, and a unique instance is thus furnished in which a complete earthquake record at one place has extended continuously over a thousand years. Of the 1318 earthquakes at Kyōto, 34 were destructive, 194 "strong," and the remaining 1090 "slight" [see Art. 50].

The total number of destructive and strong earthquakes, which happened in Kyōto between the 9th century and the present time is 228, with time distribution as shown in fig. 6; this figure indicates a well pronounced maximum from the middle of the 14th to the middle of the 15th century, and then a steady decrease to a minimum in the first half of the 19th century. The seismic activity at Kyōto seems at present to be on its way to another maximum.[1]

The variation of the yearly activity of earthquakes in Kyōto for the two most disturbed epochs, namely, the 9th century, and the interval between 1340 and 1609 shows a series of fluctuations, whose average period is about 6½ years.[2]

Ordinary Earthquakes.

15. Systematic earthquake observation throughout the Empire was first organized in 1885. The total number of earthquakes observed during the 19 years between 1885 and 1903 was 27,485, which gives a yearly average of 1447 shocks, or a daily

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[1] See also Professor Milne's "Note on the great Earthquakes in Japan," Trans. Seis. Soc., Vol. III.

[2] F. Omori: Notes on the E. I. C. Catalogue of Jap. Earthquakes; J. Sc. Coll., Vol. XI. pp. 418—434.

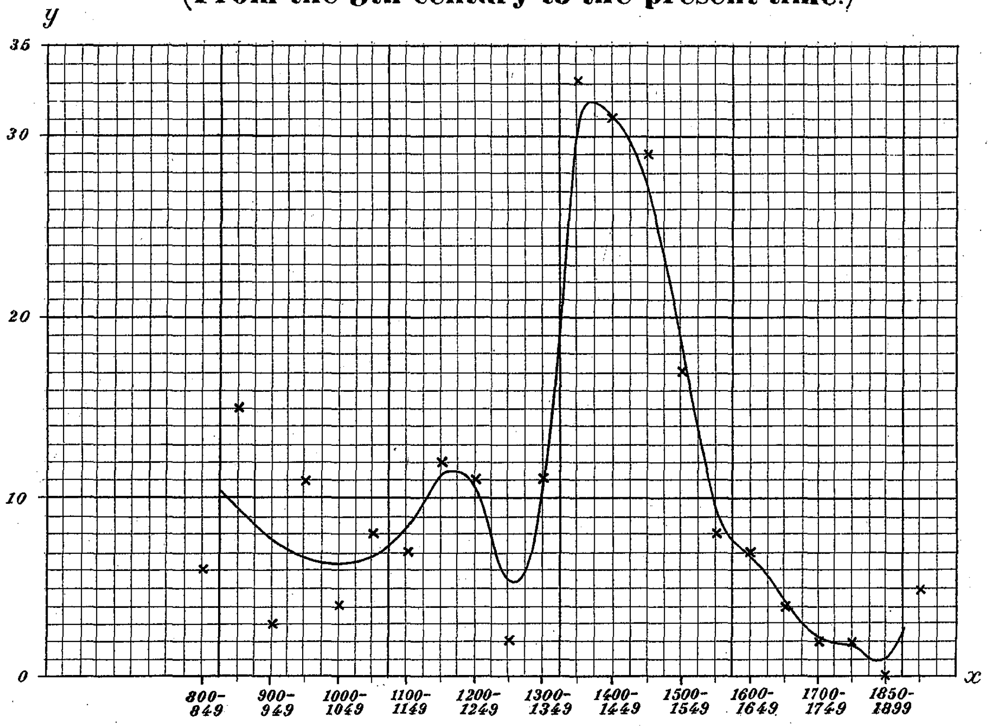
average of 4. The maximum earthquake number of 2729 occurred in 1894 and the minimum of 472 in 1886.

16. *Annual Variation of the Frequency.* There has been an enormous increase in the earthquake number since 1891: this is due to the occurrence of the Mino-Owari earthquake in Oct., 1891, and several very strong earthquakes in the subsequent years, each of these disturbances being followed by numerous after-shocks. The mean state of the seismic activity for the whole of Japan in ordinary years or those free from destructive earthquakes and their after-shocks is approximately as follows [see figs. 3 and 5 opposite p. 12]:—(1) The greatest monthly number of 65·3 occurred in May, and the smallest numbers, varying between 41·7 and 45·4, in June, July, August and September. (2) The maximum seasonal number of 172 occurred in Spring, and the minimum of 134 in Summer [cf. Art. 13.]

17. *Earthquakes in Tōkyō.* The earthquake observation in Tōkyō, in which instruments were used from the beginning, furnishes us with invaluable materials for questions connected with the annual and diurnal variations, as the records are not affected by any circumstances which may render the accuracy of the observation non-uniform in the different parts of the year or the day.

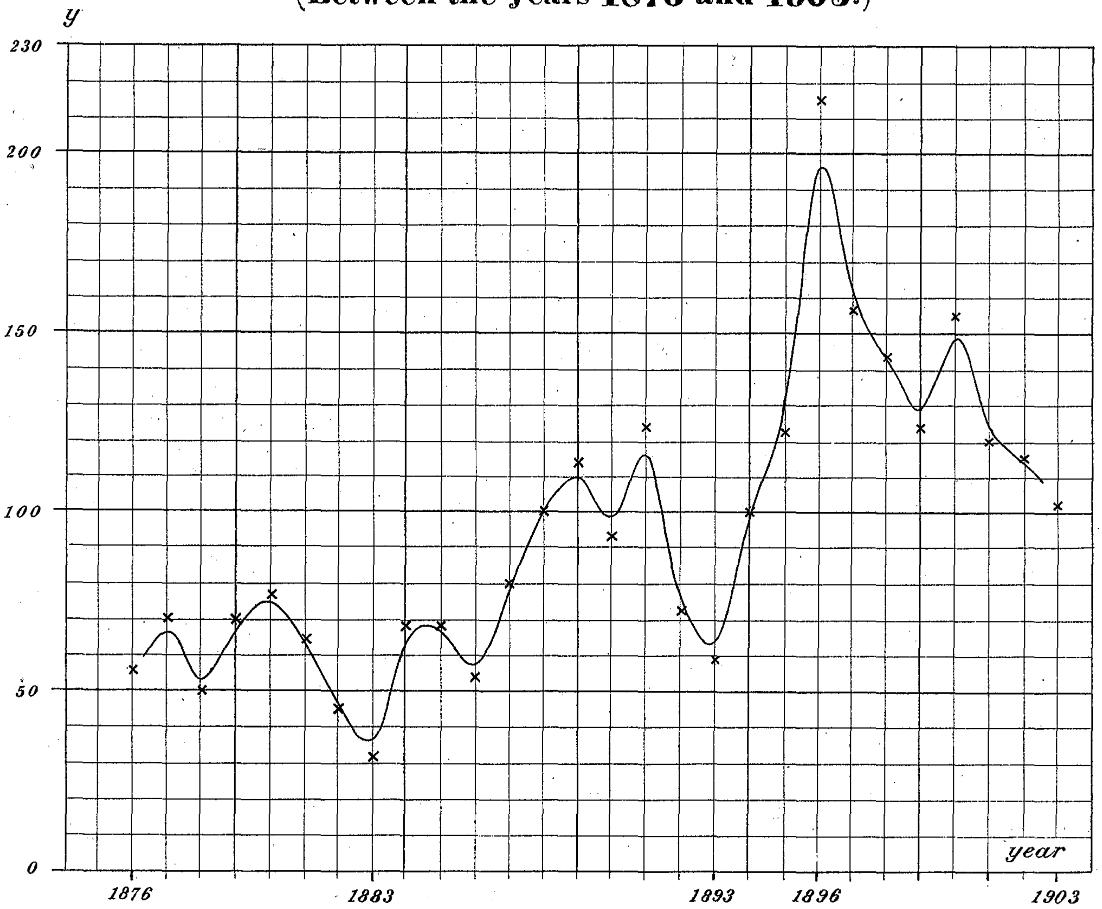
As stated in Art. 4, the earthquake observation in Tōkyō dates from the 8th year of Meiji (1875) and has now been continued for more than 28 complete years; the total number of earthquakes recorded up to the end of 1903 being 2657. The mean yearly number is 95, of which about 50 are sensible shocks. The secular variation of seismic frequency in Tōkyō is illustrated in fig. 7; the absolute minimum and maximum in the interval under consideration having occurred in 1883 and 1896 respectively. The general course of the curve seems to indicate a period of long

Fig. 6. Secular Variation of Seismic Frequency in Kyōto.
(From the 9th century to the present time.)



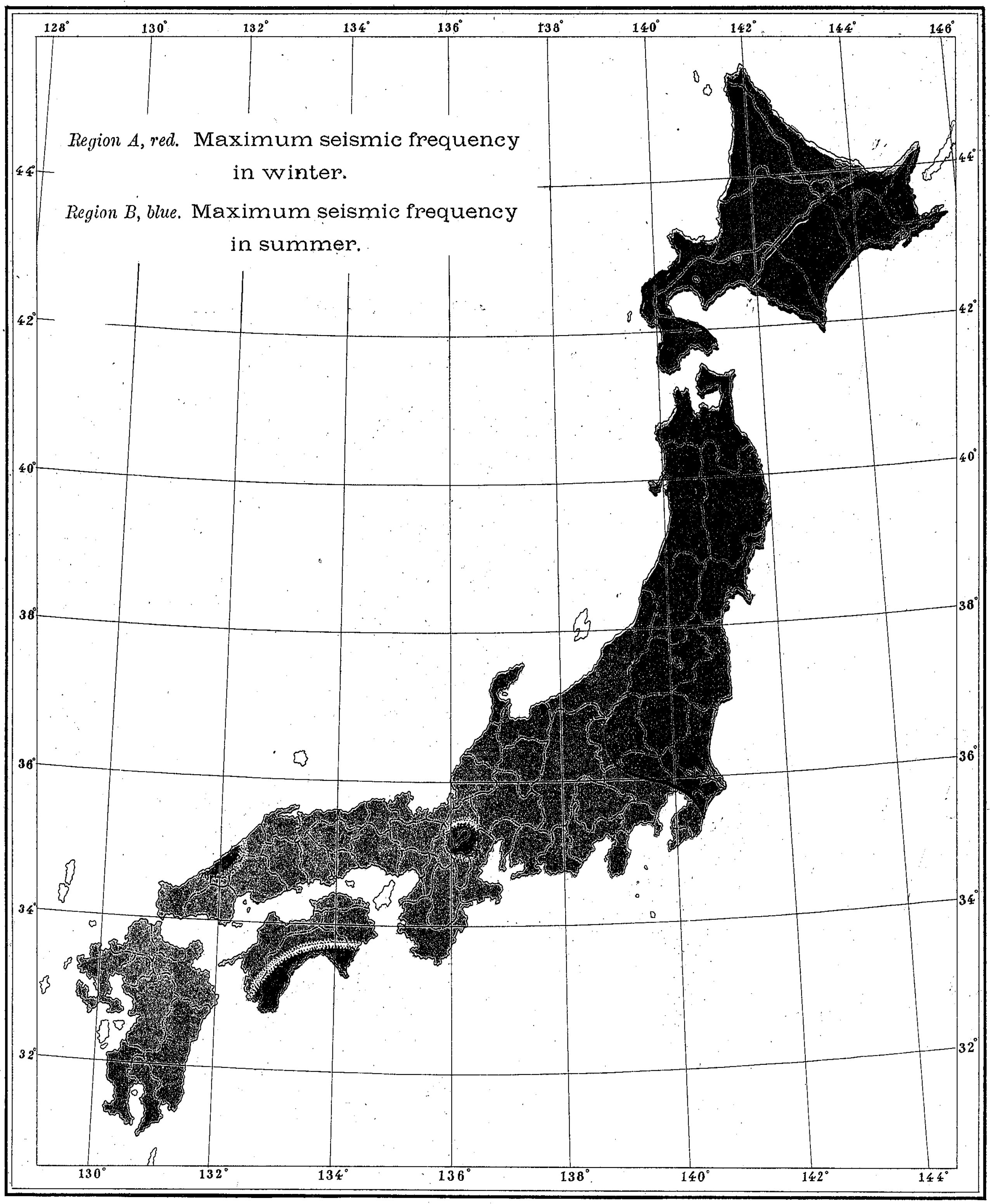
x=Time interval of 50 years.
y=Total seismic activity during 50 years denoted by x.

Fig. 7. Variation of Seismic Frequency in Tōkyō.
(Between the years 1876 and 1903.)



y=Yearly number of earthquakes in Tōkyō.

Fig. 8. Relation of Annual Seismic Variation and Geographical Position.



Region A, red. Maximum seismic frequency in winter.

Region B, blue. Maximum seismic frequency in summer.

duration, the frequency decreasing on the whole from 1896 to the present time. It is hereby to be noted that the severest earthquake in Tōkyō in recent years [Art. 66] took place in 1894, the year 1893 being one in which the frequency was a minimum. The two next severest shocks took place in 1884 and 1887, and each was preceded by a year of minimum seismic frequency.[1]

18. *Relation of Annual Seismic Variation to Geographical Position.* What has been said in Art. 16 relates to the annual variation of the seismic frequency in Japan as a whole. The time distribution of earthquakes, however, is not necessarily the same for the different parts of Japan; in fact they may, according to the character of the annual seismic variation, be divided into two nearly opposite groups *A* and *B*, as follows:—At stations belonging to the group *A*, the seasonal maximum is mostly in spring and minimum mostly in summer or autumn; while at stations belonging to the group *B*, seasonal maximum is in summer, and minimum in winter or autumn. The dependence of the annual seismic variation on the geographical position may be seen from fig. 8, in which the regions belonging to the group *A* are coloured red and those belonging to the group *B* are coloured blue. It will be seen that the regions belonging to the two groups are separated into definite areas. Thus the *B* group region includes the whole north-eastern part of Japan, that is to say, the eastern half of Hokkaidō, the San-Riku provinces, the Ryō-U provinces, Iwaki, Iwashiro, Hitachi, Shimotsuke, the northern part of Echigo, the greater portion of Kōtsuke, the northern part of Musashi and the greater portion of Shimōsa. The vicinity of Hikone (bordering on Lake Biwa) and of Hamada, and the southern part of the Island of Shikoku also

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[1] F. Omori: Notes on the E. I. C. Catalogue of Japanese Earthquakes; J. Sc. Coll., Vol. XI., pp. 435–437.

belong to the *B* group region. The *A* group region includes the western half of Hokkaidō and the whole of Japan to the west of Echigo, Musashi and the Awa-Kazusa Peninsula, with the exception of a few isolated portions, which belong to the *B* Group region, as already mentioned.[1]

With regard to this peculiar geographical relation of the annual seismic variation, Prof. Omori remarks that on the whole, the earthquakes disturbing the *A* group region have inland origin, while those of the *B* group region have their origin mostly under the Pacific: a possible explanation is therefore to be found partly in the fact that the barometric pressure is at a minimum in summer and a maximum in winter; this pressure is the principal factor in the annual variation of the seismic frequency on land; on the other hand, Prof. Omori has observed that the level of sea water is higher in summer than in winter, so that the variation of the pressure on the ocean bottom is the reverse of what it is on land.

19. *Diurnal Variation.* The diurnal seismic period is clearly shown by the after-shocks of great earthquakes. In the case of the Mino-Owari earthquake of 1891, these shocks were very numerous, the successive hourly (or a-few-hourly) earthquake numbers, registered instrumentally at Gifu and Nagoya, indicating well-defined diurnal fluctuations.[2] The cause of the diurnal seismic variation seems to be the changes of the atmospheric pressure.

As an example, let us consider the diurnal variation in Tōkyō. Fig. 9 shows 3 hourly distribution of 2208 earthquakes instrumentally observed during the 24 years between 1876 and 1899; the

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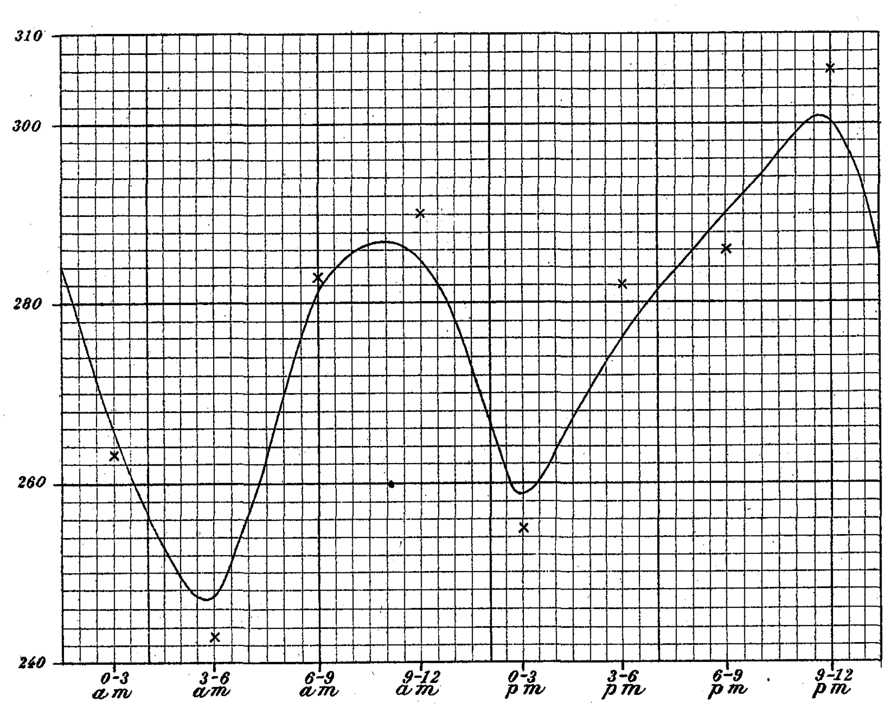
[1] F. Omori: Annual and Diurnal variation of Seismic Frequency in Japan; E. I. C. Publ., No. 8, pp. 5–52, or E. I. C. Hō. No. 30, pp. 34–78.

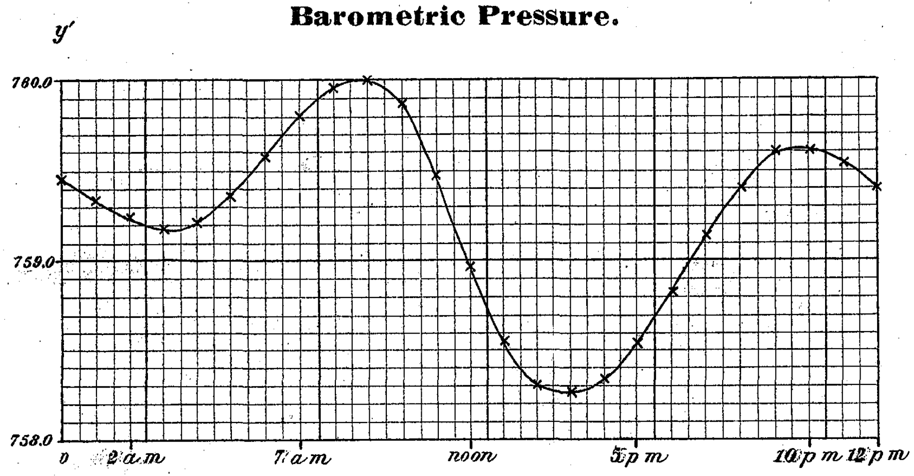
[2] F. Omori: On the After-shocks of Earthquakes; Jour. Sc. Coll., Vol. VII.

Fig. 9. Diurnal Variations of Seismic Frequency and Barometric Pressure in Tōkyō.

Seismic Frequency.



Barometric Pressure.



y=3-hourly number of earthquakes.
y'=Mean barometric height in mm

curve indicates two maxima and two minima, while the curve of the barometric pressure indicates also two maxima and two minima. The forms of the two curves are very similar and nearly parallel to one another, the maxima and minima occurring at almost the same hours for both.

The diurnal variation for the whole of Japan shows approximately the same result. As, however, we may expect for some places to find the harmonics, or 12, 8, 6,...hours periods in the diurnal seismic variation, and as one or other of these various periods may predominate at each place, we may suppose the diurnal variation of seismic frequency to be a good deal different for different stations. An examination of the diurnal variation for different localities shows that they may be divided into four different groups according to the predominance in the diurnal fluctuation of 12, 8, 6, or 4 hours period.1)

20. The study of the after-shocks of recent destructive earthquakes in Japan has indicated the existence, beside the annual and diurnal periods, of four others whose lengths were respectively 4½ days, 12 days, 33 days, and about 3 months.

Prof. Omori has also shown that, with regard to the relation between the atmospheric pressure and seismic frequency other than the annual and diurnal variations, the seismic frequency may be accompanied by a maximum, minimum, or increasing or decreasing atmospheric pressure, according to the origin and cause of the earthquakes.2)

21. *Lunar Day Distribution of Earthquakes.* Fig. 10

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1) F. Omori: Annual and Diurnal Variations of Seismic Frequency in Japan; E. I. C. Publ. No. 8, pp. 53–94, or E. I. C. Hō, No. 30, pp. 78–116.

2) F. Omori: Note on the Relation between earthquake Frequency and the atmospheric Pressure; Tōkyō Sūgaku Butsurigakkwai Kiji Gwaiyō (Proceedings of the Tōkyō Mathematical and Physical Society, referred to subsequently as Su. Buts. K. G.), Vol. II, No. 8.

shows the distributions in the lunar day of 1270 earthquakes at Nagoya, 799 earthquakes at Nemuro, and 1462 earthquakes at Tōkyō, respectively; the lunar day, counted from 0 to 24 hours, being the time interval between the two successive meridian transits at Tōkyō. The observations at Nagoya and Nemuro are respectively those of the after-shocks of the great Mino-Owari earthquake of 1891, and of the Hokkaidō earthquake of 1894; while the Tōkyō observations relate to ordinary shocks. Again, the earthquakes at Nagoya were almost entirely of inland, and those at Nemuro of submarine origin, and those at Tōkyō of mixed origin. Notwithstanding these differences in the origin, the curves of the lunar-day variation are nearly identical in character, each showing two maxima which occur respectively near or at the moon's upper and lower culminations.¹⁾

According to Dr. K. Honda, this dependence of the seismic frequency on the position of the moon is due probably not to the direct lunar attraction but to the tidal movement of the sea water which follows the motion of the moon.²⁾

22. *Synodic-monthly Variation of Earthquakes.*³⁾ Distributing in the 30 synodic days the 1898 Japan historical earthquakes, the seismic frequency is found to be at a maximum not only at the times of the conjunction and opposition of the sun and moon, but also at the times of quadrature. This is also found to be nearly the case, from recent observations at different Meteorological stations, with earthquakes of submarine origin. On

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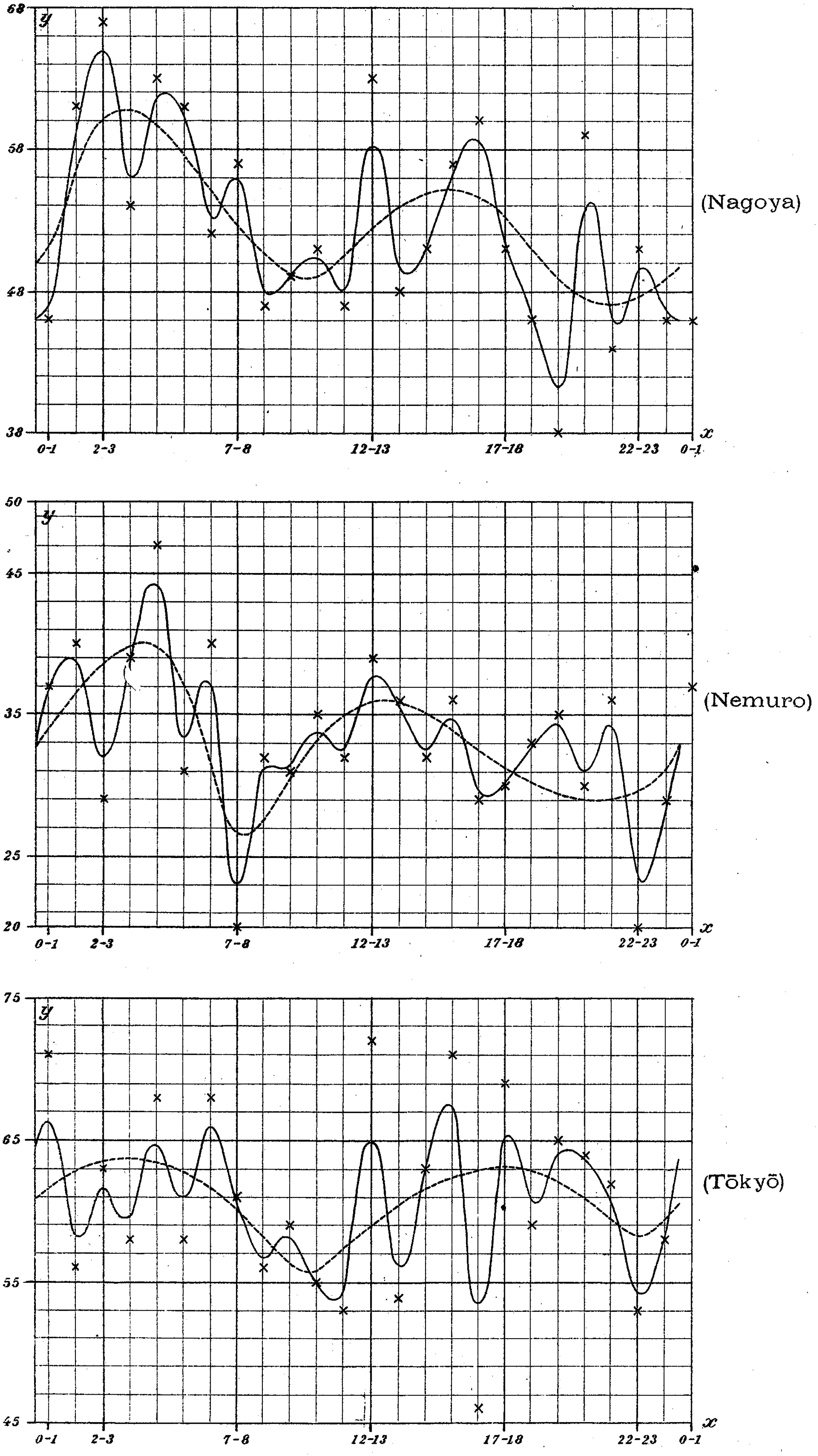
1) F. Omori: Note on the Relation between the Seismic Frequency and the Position of the Moon; E. I. C. Hō No. 32.

2) K. Honda: Daily periodic Change of the Level in the Artesian wells in Yokohama and Okubo; Su. Buts. K. G., Vol. II, No. 9.

3) A. Imamura: Synodic-monthly Variation of Seismic Frequency in Japan; Su. Buts. K. G., Vol. II, No. 8.

Fig. 10. Lunar-daily Distribution of Earthquakes.



x=Lunar hour.
y=Hourly number of earthquakes.

the other hand, those localities, which are shaken by earthquakes of inland origin are characterized by two maximum seismic frequencies at the days of the conjunction and opposition of the sun and moon. Finally of the 90 destructive shocks in Japan which occurred near the sea-coast, 29 occurred between 22nd and 26th days, 21 between 5th and 9th, 13 between the 14th and 18th, and 10 between the 28th and 2nd. The following may be regarded as an explanation for the existence of a pair of maximum frequency at the times of quadrature:—The barometric pressure which reaches its maximum in its diurnal variation at 9h and 22h, interferes with the tidal force, helping the latter when high water occurs at these hours, and cancelling it when low water takes place then.

After-shocks of Earthquakes.

23. A great earthquake is almost invariably followed by weaker ones, and when it is violent and destructive, the number of minor shocks following it may amount to hundreds or even thousands and continue for several months or several years. Complete instrumental records of these secondary shakings or *after-shocks* were first obtained in the cases of the Mino-Owari earthquake of 1891 and other great disturbances of recent years in Japan.

The occurrence of after-shocks is quite natural and necessary for the settling down into stable equilibrium of the disturbed tract at the origin of disturbance; each of these shocks removing an unstable or weak point underneath. Further, as a very great shock would remove a correspondingly great underground instability, it is probable that such a shock would not, for a long time, be followed by another of a magnitude comparable to its own, in the same or a neighbouring district. When, however, the initial shock is not very great, it may be followed by another like it, but, even in this case, the position of the origin of the second shock would usually be quite distinct from that of the first.[1]

The frequency of after-shocks at a given distance from the origin is different for different earthquakes and depends mainly on the magnitude of the initial earthquake. Thus, in the case of the Mino-Owari earthquake, more than 4000 shocks were recorded at Gifu in the course of the six years following the initial disturbance.

24. *Time Variation of the Frequency of After-shocks.* The mean time variation of after-shocks follows a very simple law and may be represented by means of a rectangular hyperbola. [See fig. 11.] Thus, denoting by x the time and by y the corresponding frequency of after-shocks, we have the following relation: $y=\frac{k}{h+x}$, in which k and h are constants to be properly determined for each case.

The Mino-Owari earthquake took place on Oct. 28th, 1891, at 6h 37m a.m. (Gifu). Taking the semi-daily earthquake numbers observed instrumentally at the Gifu meteorological station during the five days between Oct. 29th and Nov. 2nd, 1891, and calculating by the method of Least Squares, the above equation assumes the form $y=\frac{440{\cdot}7}{x+2{\cdot}314}$, in which y denotes the number of earthquakes observed at Gifu during the 12 hours denoted by x; the time origin, expressed by $x=0$, corresponding to the first half of Oct. 29th, 1891.[2]

As a test of the accuracy of the above equation, which was

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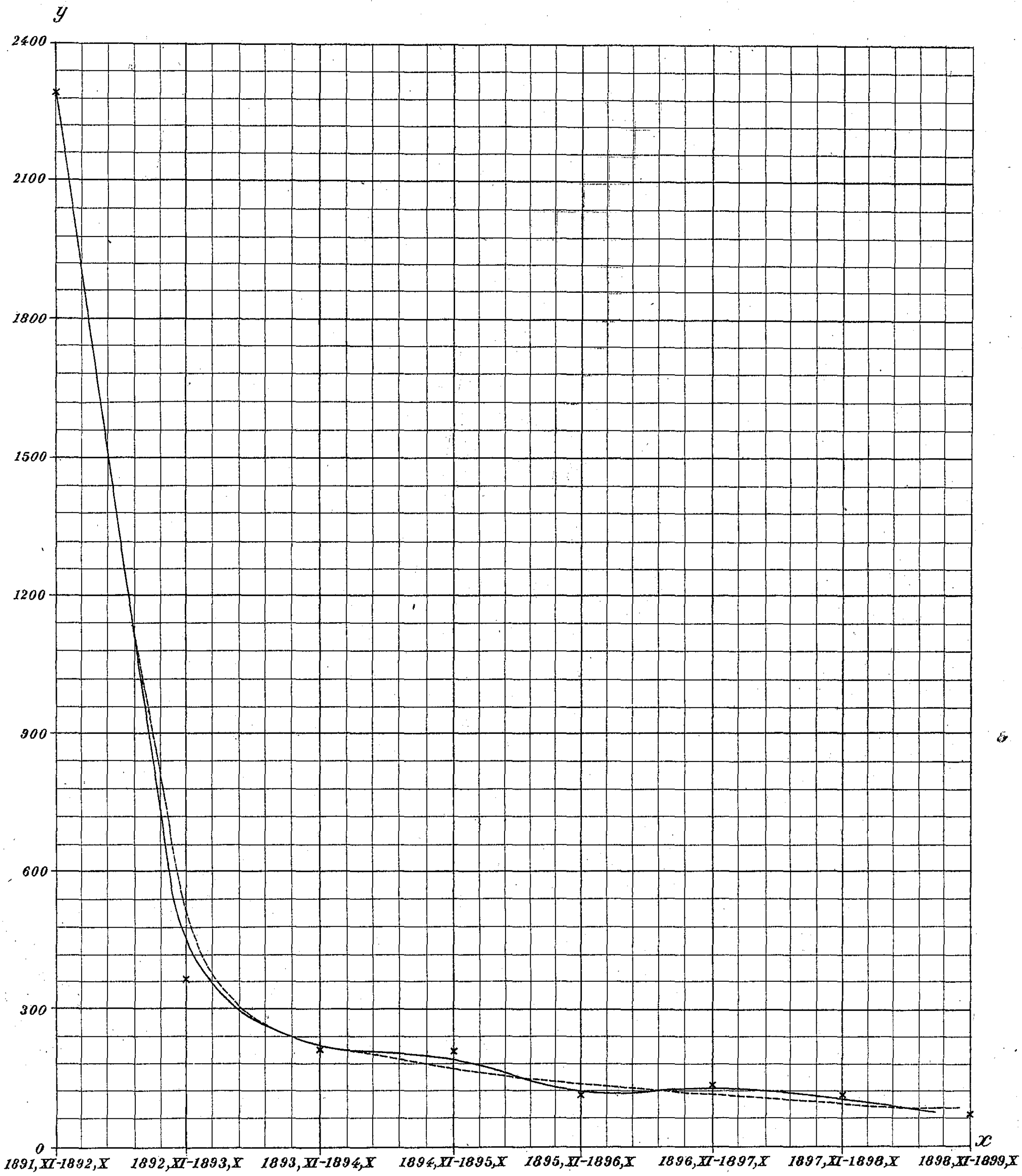
1) F. Omori: On the After-shocks of Earthquakes; Jour. Sc. Coll., Vol. VII.

2) F. Omori: Ib.

Fig. 11 Time Variation of the Frequency of the Mino-Owari After-shocks. (Gifu).



x=Time interval of 12 months.
y=Number of earthquakes at Gifu during the 12 months denoted by x.

published in 1894, the seismic frequencies at Gifu for 1898 and 1899 calculated by it may be compared with the numbers of the earthquakes actually observed there during these two years. Thus the equation in question gives for the theoretical total numbers of after-shocks at Gifu for the two years the numbers 66 and 57 respectively. It is, however, to be remembered that the equation has been deduced simply from the observations at Gifu during the first 5 days and is not affected by ordinary earthquakes or those which are not after-shocks of the Mino-Owari earthquake. Hence for the theoretical numbers of all earthquakes at Gifu during the two years under consideration, the above must each be increased by the mean annual seismic frequency at Gifu in ordinary years, which was about 18·3. Thus the calculated earthquake numbers come out finally to be 84·3 and 75·3 respectively, or together 160. Actually there were 101 and 62 earthquakes respectively in 1898 and 1899, or 163 during the two years; these numbers agreeing with the calculated results as closely as may be expected.1)

Similar calculations have been made, with equally satisfactory results, for the after-shocks of the Hokkaidō earthquake of March 22, 1894,2) and those of the great Ansei earthquake of Dec. 24, 1854.3)

Dr. Enya has recently arrived at another equation expressing the relation between the time and the frequency of after-shocks,

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1) F. Omori: Note on the After-shocks of the Mino-Owari Earthquake of Oct. 28th, 1891; E. I. C. Publ., No. 7.

2) F. Omori: Note on the After-shocks of the Hokkaidō Earthquake of March 22nd, 1894; E. I. C. Publ., No. 4.

3) F. Omori: 2nd report on the After-shocks of Earthquakes; E. I. C. Hō., No. 30.

which also gives results agreeing tolerably well with the observed numbers.[1]

(E) Geographical Distribution of Earthquakes.

Destructive earthquakes.

25. *Frequency.* The geographical distribution of the destructive earthquakes from the earliest times (5th century) down to the present day is shown in fig. 12. No destructive earthquake has occurred in the seven provinces of Iki, Oki, Tajima, Shiribeshi, Kitami, Hitaka and Tokachi; only one each in the seven provinces of Chikugo, Buzen, Suwō, Hōki, Mimasaka, Ishikari and Teshio; more than eleven in each of the fourteen provinces of Yamashiro, Yamato, Kawachi, Settsu, Kii, Ise, Shinano, Mikawa, Tōtōmi, Suruga, Sagami, Musashi, Shimotsuke and Iwashiro; between six and ten in each of the thirteen provinces of Iyo, Izumi, Iga, Ōmi, Echizen, Mino, Owari, Kai, Izu, Shimōsa, Hitachi, Echigo and Rikuzen; and between two and five in each of the remaining forty-two provinces.[2]

26. *The Area of Earthquake Disturbances.* Let us for the sake of convenience distinguish destructive earthquakes, according to the magnitude of the area of disturbance, into two kinds, namely, *local* earthquakes, in which the area of destructive motion was confined to only one province, and *non-local* earthquakes, in which the area extended over several provinces. According to this convention, the 223 destructive earthquakes may be divided into 149 local and 74 non-local ones, the ratio of these two numbers

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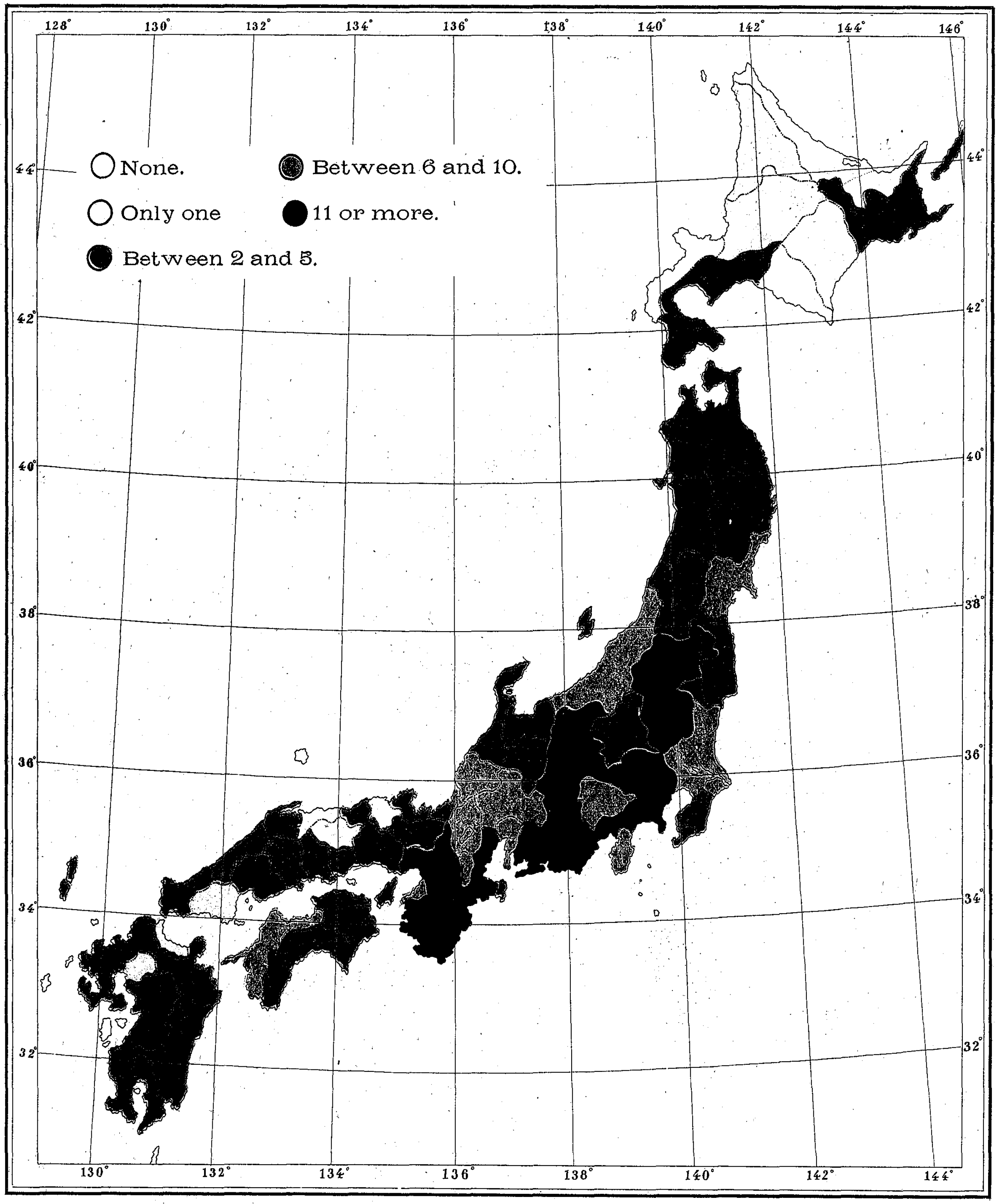
1) M. Enya: On the After-shocks of Earthquakes; E. I. C. Hō., No. 35.

2) F. Omori: Notes on the E. I. C. Catalogue of Japanese Earthquakes; Jour. Sc. Coll., Vol. XI. Notes on great Earthquakes in Japan; E. I. C. Hō., No. 32.

Fig. 12. Distribution of Destructive Earthquakes in Japan
(Formosa and Lyū Kyū excepted)
From the 5th century to the present time.



being as 2:1. Further, it is to be noted that the provinces of Ōsumi, Satsuma, Higo, Hizen, Chikuzen, Tsushima, Iwami, Izumo, Kaga, Noto, Sado, Echigo, Shinano, Shimotsuke, Iwashiro, Uzen, Ugo, Ishikari and Teshiwo were generally disturbed by local shocks; non-local ones originating very rarely in these provinces, with the exceptions of Shinano and Echigo. On the other hand, Hyūga, Bungo, Tosa, Kii, Mino, and the provinces of Kinai and Tōkaidō were often disturbed by great non-local shocks, of which the origins were generally situated off the eastern coast of Japan, and which were probably caused by faults formed parallel to the latter.

The three north-eastern provinces of Rikuzen, Rikuchū and Nemuro were often disturbed by great earthquakes of sub-oceanic origin. The areas of destructive motion in these cases seem never to have extended to the south of Hitachi and the Peninsula of Kazusa and Awa. Now, as is well known, the group of the Japanese islands forms an arc, with its concavity turned towards the Japan Sea, and the general geographical distribution of destructive earthquakes in Japan may be summarised as follows. The provinces on the concave or Japan-Sea side of the arc were disturbed almost exclusively by local shocks; while those on the convex or Pacific side of the arc were often disturbed by great non-local ones, whose origins were situated in the Ocean, sometimes accompanied by "*tsunami.*" Of the provinces in the central portion of the Main Island, Mino, Shinano, Shimotsuke and Iwashiro often became the seats of local destructive earthquakes. But the two other provinces of Kōtsuke and Hida were very seldom disturbed by destructive earthquakes, and form, together with Tajima and a few provinces in Sanyodō, the regions seismically most stable in the Main Island.

27. *Origin.* What has been said above relates to the frequency of destructive earthquakes in the different provinces of the Empire. Examining now the 223 large shocks recorded since the earliest times with respect to their origins, the approximate results are as follows:—

Origin in the Pacific,	47	earthquakes.
,, ,, Japan Sea,	17	,,
,, ,, Inland Sea,	2	,,
,, inland,	114	,,
(,, obscure,	43	,,)

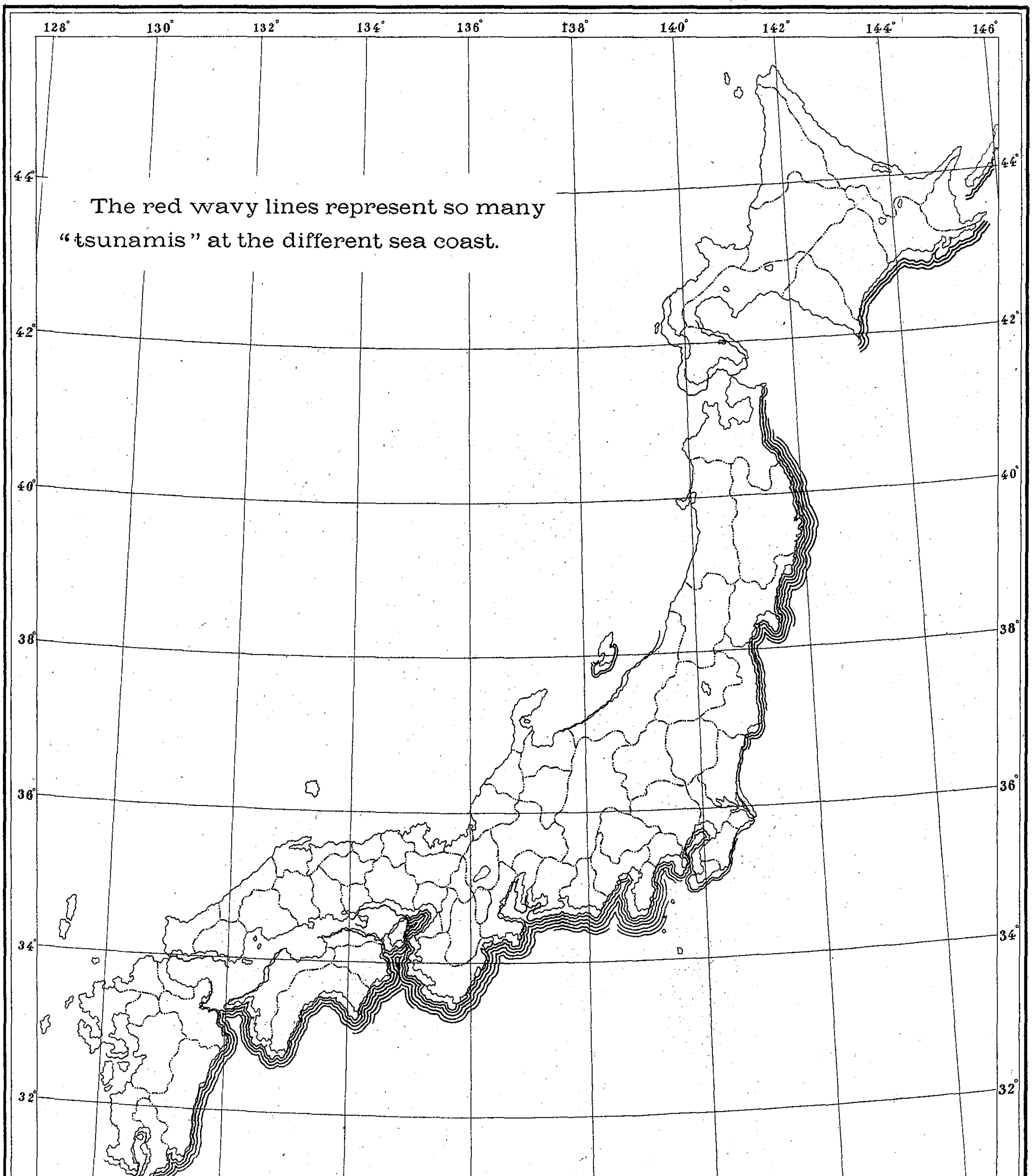
Thus the numbers of the earthquakes of the Pacific, Japan sea, and inland origins were as 3:1:7.

Of the 47 destructive earthquakes of Pacific origin, 23 were accompanied by *tsunami* which often caused much greater damage than the earthquakes themselves. From fig. 13, which shows the distribution of the *tsunamis* (accompanying earthquakes) along the coast of Japan, it will be seen that, they were almost entirely confined to the Pacific coast, the only exceptions being two along the coasts of Echigo and Sado; the provinces most often devastated were Izu, Awa (in Shikoku), Settsu, Tōtōmi, Rikuchū, and Mutsu.

Among the 223 destructive earthquakes, there were 10, which were especially great. Of these, seven originated off the south-eastern coast and were each accompanied by destructive *tsunami*; while the remaining three were of inland origin and shook the central parts of the Main Island.

The greatest among the ten earthquakes above referred to was that of the 4th year of Hōei (Oct. 28, 1707), the destructive area including the eastern part of Kyūshū, the Island of Shikoku, and the southern part of the Main Island between the province of

Fig. 13. Map showing the Distribution of the " Tsunamis " accompanying Earthquakes. (From the 5th Century to the present time.)



The red wavy lines represent so many " tsunamis " at the different sea coast.

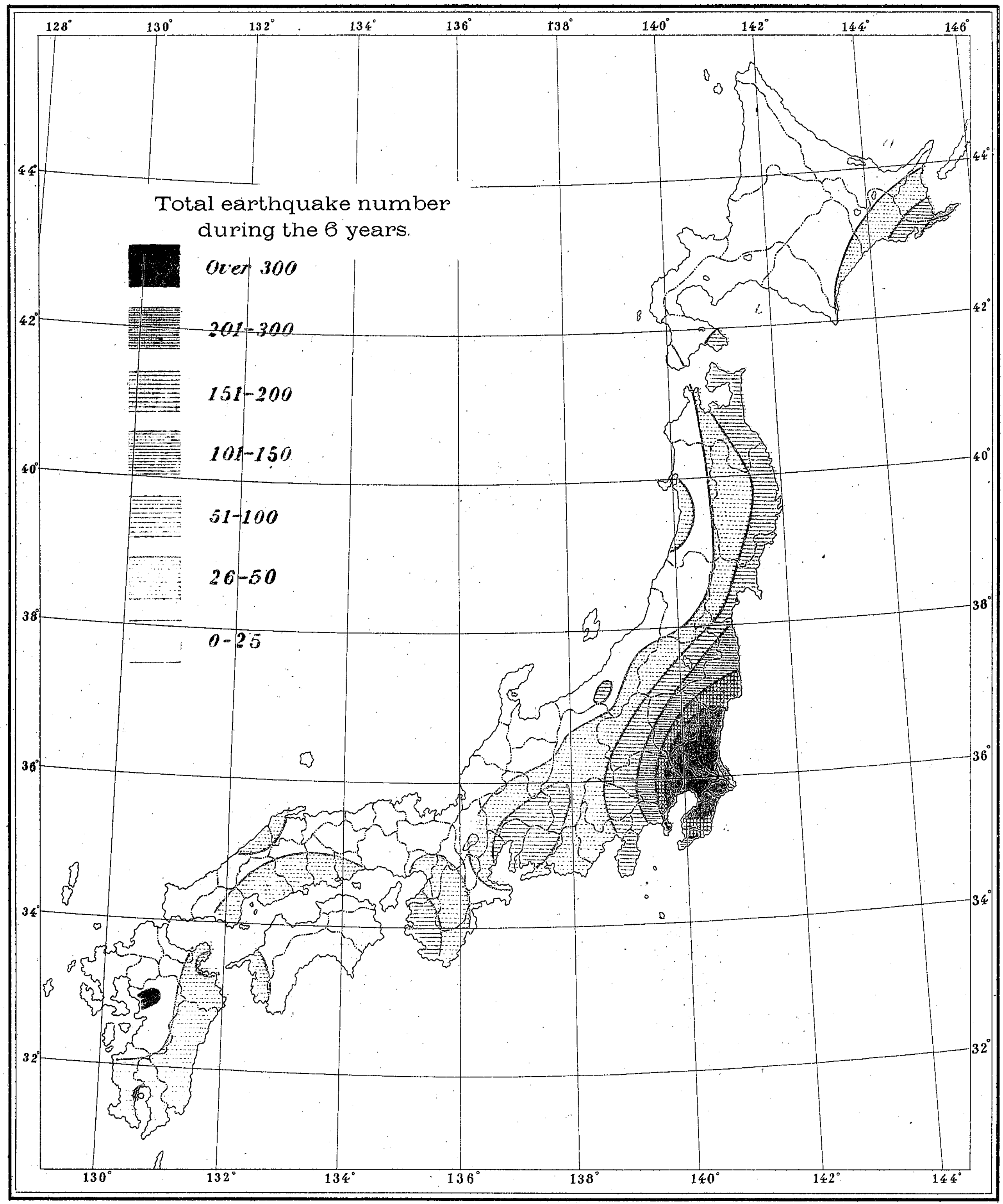


Fig. 14. Map showing the Frequency of Earthquakes, during the six years between 1885 and 1890.

Harima on the west and the provinces of Kai and Suruga on the east.

Ordinary earthquakes.

28. *Frequency.* Fig. 14 shows the frequency of earthquakes in the different parts of Japan during the six years between 1885 and 1890.[1] As there was no destructive earthquake during this interval, except that of Kumamoto, July 28, 1889, the map may be regarded as fairly showing the seismic state of the country in *ordinary* years. It will be observed that earthquake frequency is much greater along the eastern coast of the Islands than along the western.

29. *Origin.* The distribution of the earthquake origins in Japan seems to have a close connection with the curvilinear form of the country; they are arranged approximately in two systems which are respectively parallel and normal to the arc formed by the Japanese islands.

Tsunami.

30. As stated above [Art. 27], a large number of destructive earthquakes of Pacific origin were accompanied by *tsunami.* One of the most destructive seismic *tsunamis* in recent years took place on June 15th, 1896, the whole north-eastern coast of the Main Island for a length of 250 miles being devastated. A report of this catastrophe is given in E. I. C. Hō., No. 11, by Dr. T. Iki.[2]

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[1] The map is taken from the *Earthquake Reports*, published by the Central Meteorological Observatory.

[2] See also Dr. A. Imamura's Note "On the great tsunami of 1896," in E. I. C. Hō., No. 29.

In E. I. C. Hō., No. 34, Prof. Omori gives the result of the examination of the tide-gauge diagrams at several stations on the Pacific coast of Japan and arrives at the conclusion that different parts of the coast have their proper period or periods of waves, that is to say, each particular portion of sea coast is virtually a fluid pendulum whose boundaries are determined by the form of the bottom and the contour of the shore line. Accordingly, the wave period or periods at a given place on a given coast remain constant in all the *tsunamis*, irrespective of the origin or cause; a destructive *tsunami* consisting simply in the amplification of the amplitude of the wave motion existing more or less at all times, in consequence of a strong submarine earthquake, a storm, or some other agency. Seismic *tsunamis* occur very often along the Pacific coast, each strong submarine earthquake being always accompanied, or rather followed, by some amount of sea water disturbance. A seismic *tsunami* is caused, according to Prof. Omori, by the movements communicated from the sea bottom to the superincumbent water; a very big *tsunami* taking place when the earthquake focus is at the sea bottom itself or at a very small depth below it. [See also Art. 100.]

CHAPTER III. INSTRUMENTAL INVESTIGATIONS.

31. In order to obtain a more accurate knowledge of the nature of the earthquake movements, it is necessary to have instruments which will enable us to obtain records of the movements while they are actually taking place, that they may be studied at leisure afterwards; these records must not only be very accurate, but must indicate movements which we could not have perceived at all without them. Hence from the first, the devising and improving of seismometers and seismographs have engaged the attention of seismologists.

The E. I. C. has spared no pains in order to secure good seismographs, and in making careful observations with them. The records so obtained have been carefully examined, and many important conclusions have been deduced, concerning the vibrations of the earth particles. I shall first give a short account of the instruments.

(A) Seismographs and Seismometers.

32. It would be too long and out of the scope of the present address to give an account of various contrivances and instruments that have been suggested or been actually used, interesting as it would be. I shall here simply give a short description of the seismographs or seismometers, actually set up at present in the Seismological Institute of the Tōkyō Imperial University; most of the various instruments have there been tried, and those now there have been left, as the fittest, to survive.

As it is not easy or convenient to take a record of movements of an earth particle in three dimensions at once, we take them separately for the horizontal and the vertical motions. We thus have two divisions of seismographs, one for recording the motion in the horizontal plane, and the other for the vertical motion.

Instruments for recording the horizontal motion.

33. The essential in all seismographs is a steady point, a point which shall not be displaced by the shock, and which is in a state of neutral equilibrium, so that when the shock comes and the earth moves, this point will remain at rest and therefore be displaced relatively to the earth; being in neutral equilibrium, it will remain in this position. Thus as the earth moves, this point always remains in its original position, and a pointer attached to this point will trace out on a surface fixed to the earth the movements of the point relatively to the earth, that is, the motion of the earth particle. Practically of course it is impossible to obtain a point which is absolutely steady or in absolutely neutral equilibrium. We must be content with an approximation to these conditions.

34. *Duplex Pendulum Seismometer.*[1] This is a "a combination of a common with an inverted pendulum. The common pendulum is stable, the inverted pendulum with a rigid pivoted supporting rod is unstable: by placing an inverted pendulum below a common one and connecting the bobs so that any horizontal

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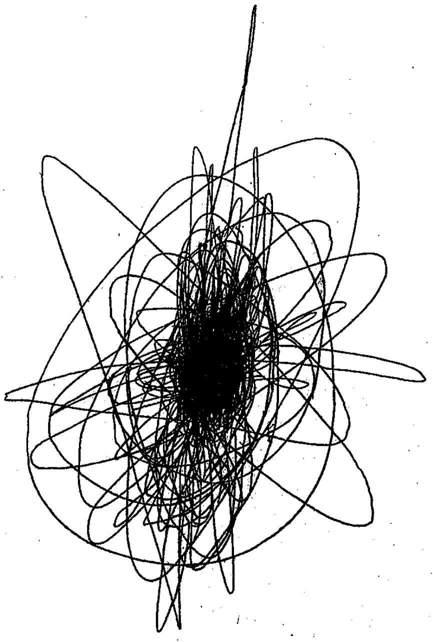
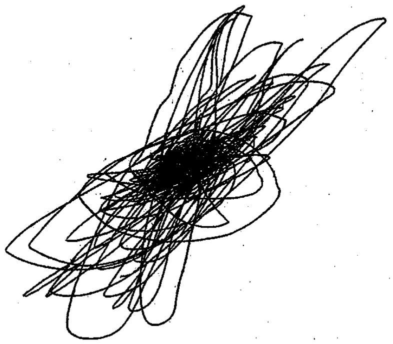
[1] For full description of this instrument, see Ewing, Seismological Notes, Trans. Seism. Soc., Vol. V; Ewing, On a Duplex Pendulum Seismometer with a single bob, ditto, Vol. VI; Sekiya, On Prof. Ewing's Duplex Pendulum Seismometer, (the actual instrument being of the construction described in this paper), ditto, Vol. VIII; Milne, Modern forms of Pendulum Seismometer, ditto, Vol. XII; Ewing, Earthquake Measurements, Memoirs of Science Dept. of Tōkyō Univ., No. 9.

Fig. 15. Duplex Pendulum Seismograph.

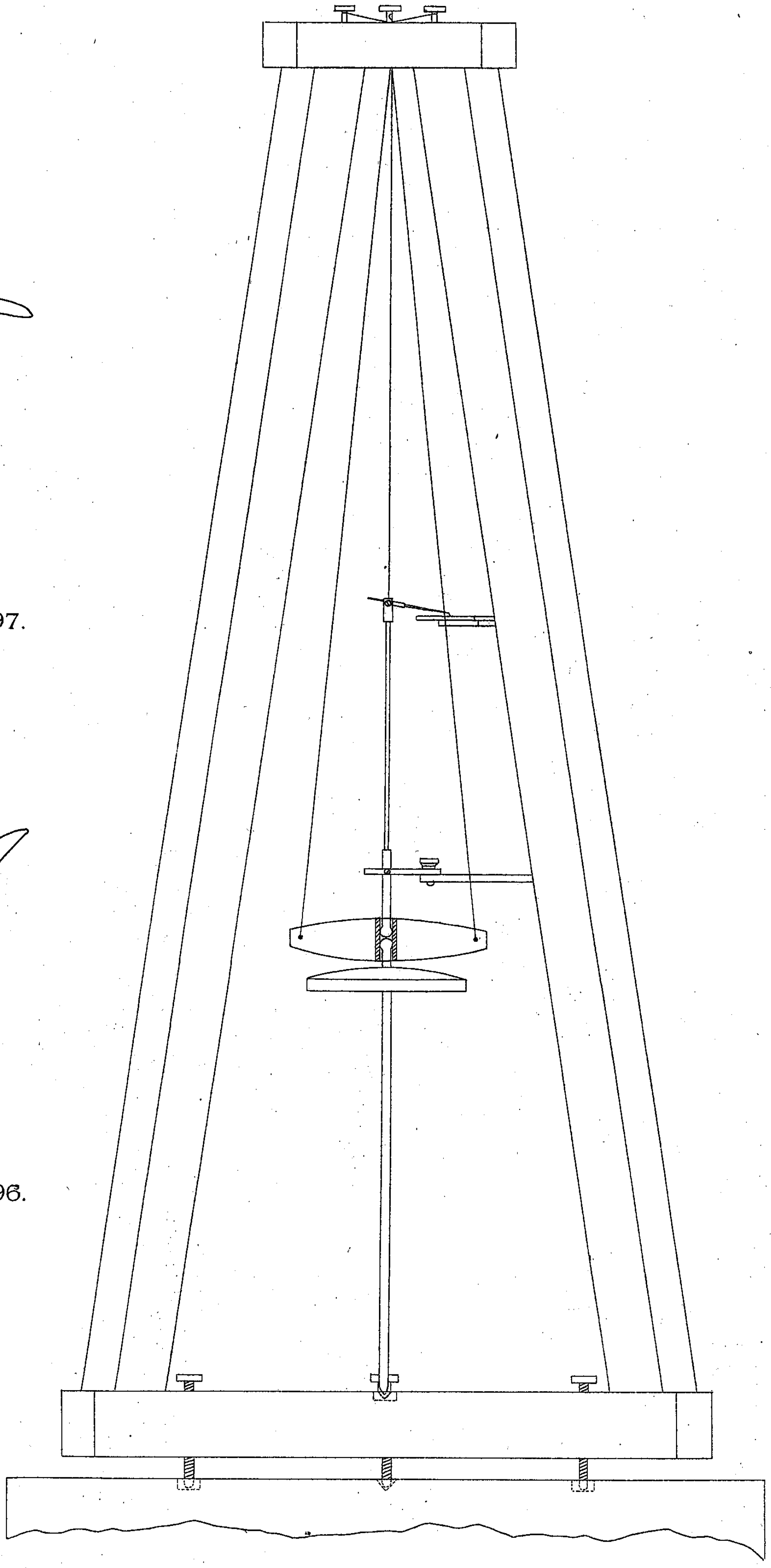


Earthquake of Aug. 27, 1897.



Earthquake of April 20, 1896.

Multiplication 7 times.



displacement must be common to both, we may make the equilibrium of the jointed system neutral or as feebly stable as may be desired.'' A pointer attached to the steady point so obtained is made to trace out the motion on a stationary smoked glass plate. [See fig. 15.]

The record thus obtained, however, being statical is not of very great use in accurate measurements. It is more convenient to obtain the records of the horizontal motion decomposed into two rectangular components, such as N-S and E-W. This is the case in all other instruments.

35. *Ewing's Bracket or Horizontal Pendulum Seismograph.*[1] The chief parts of this instrument are shown in fig. 16. [See also fig. 21.] The steady point or rather line is furnished by the axis *dd* of the heavy bob B of the pendulum in the form of a cylinder or a truncated cone, pivoted along its axis *dd* to a frame, which itself is pivoted about a nearly vertical axis *ac* to a stand fixed to the base plate; the whole thus forms a horizontal pendulum turning about this axis. The axis of the bob is the instantaneous axis corresponding to the axis of support. Thus when the shock comes, in the plane of the axes the pendulum simply suffers a displacement as a whole, but if the ground moves through any small distance horizontally and perpendicularly to this plane, then the system turns about the fixed axis and remains in that position. A pointer attached to this traces out this motion of the mass relatively to the earth multiplied any required number of times, on a revolving smoked glass plate.

Two such pendulums placed at right angles to each other will trace out the rectangular components of the earth motion.

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[1] Ewing: On a New Seismograph for Horizontal Motion, Trans. Seism. Soc., Vol. II. Also Ewing, Earthquake Measurement: Memoir of the Sc. Dept., No. 9.

This instrument was first publicly described by Prof. Ewing before the Seismological Society of Japan on Dec. 22nd, 1880.

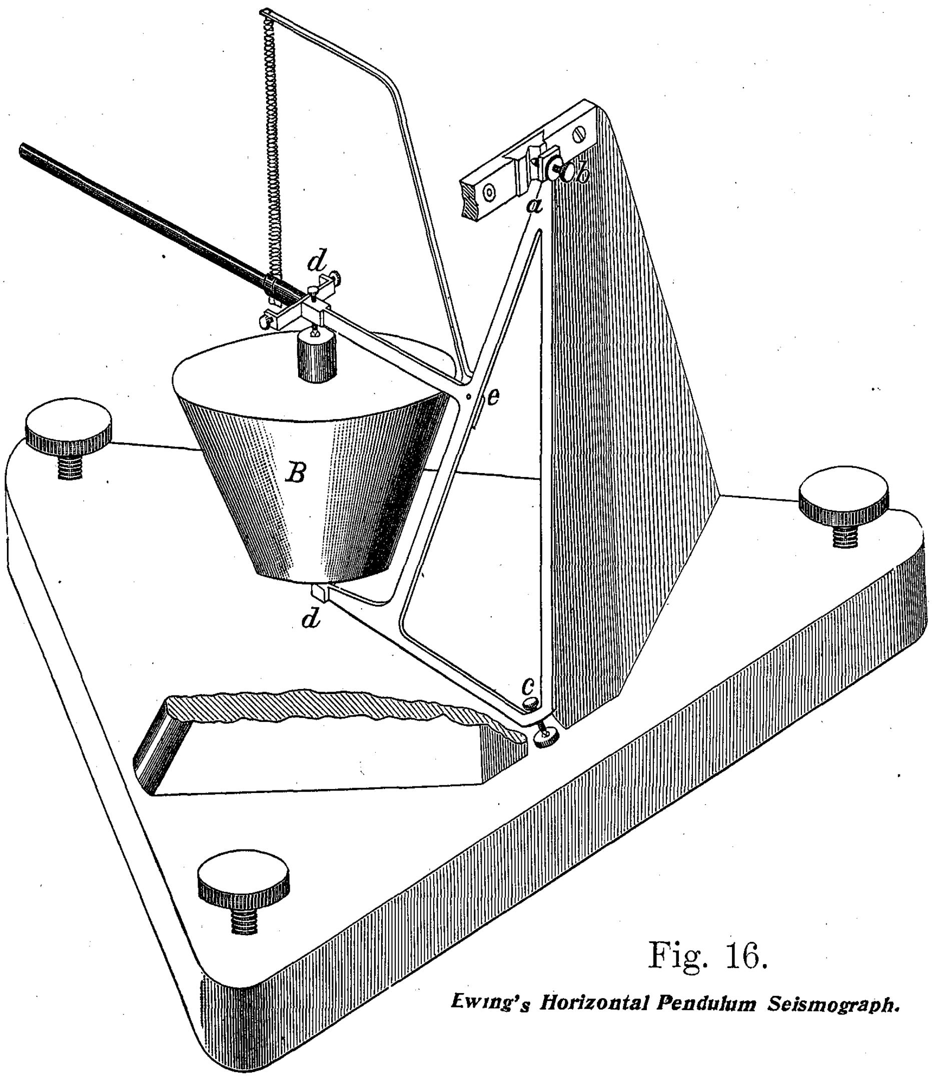


Fig. 16.

Ewing's Horizontal Pendulum Seismograph.

36. In the actual instruments, various modifications have been introduced which experience and a fuller knowledge have shown to be desirable. There are several sets of the instruments of this type, set up in the Institute, differing more or less in their arrangements. In the usual form, the pendulum has a short period of about 2½ seconds and can therefore be relied upon only for ordinary earthquake motion. In others, one of which was specially designed by Prof. Sekiya, the period is much longer, and the distance between the axes much greater, thus enabling us to get reliable records of strong earthquakes. In two of them, the record is taken on a revolving glass plate according to Prof. Ewing's original design, while in others it is taken on a band of smoked paper wound round a revolving drum having at the same time a slow motion of translation in the direction of its axis: the latter form suggested by Prof. Milne is in many respects more convenient than a glass plate, but the objection to it is that it increases the friction of the pointer; by various devices, however, this has been made so slight, as to make this arrangement preferable.

The glass plate or the drum is started by an automatic starter when the shock comes, and is kept revolving by clockwork. The starter is either electrical or mechanical. The electrical starter is nothing more than a modification of Palmieri's circuit closing seismoscope and consists of an ordinary short pendulum suspended from the top of a fixed frame; the bob is a cylinder having a small conical socket in its lower surface. A wire fits into this socket, and is held in a vertical position and pressed against the bob, by a thin narrow strip of steel, projecting from the side of the frame and attached to the wire near its upper end. The lower end of the wire, which is connected with one pole of an electric battery hangs over the center of a ring of mercury which is connected with the other pole of the battery. The bob is displaced by a shock, and with it the upper end of the wire, which then moves about the point of attachment of the steel strip, thus causing the lower end to come in contact with the mercury: this closes the circuit and an electric current is started, which by means of an electro-magnet rings a bell and sets free the clockwork turning the plate or the drum.

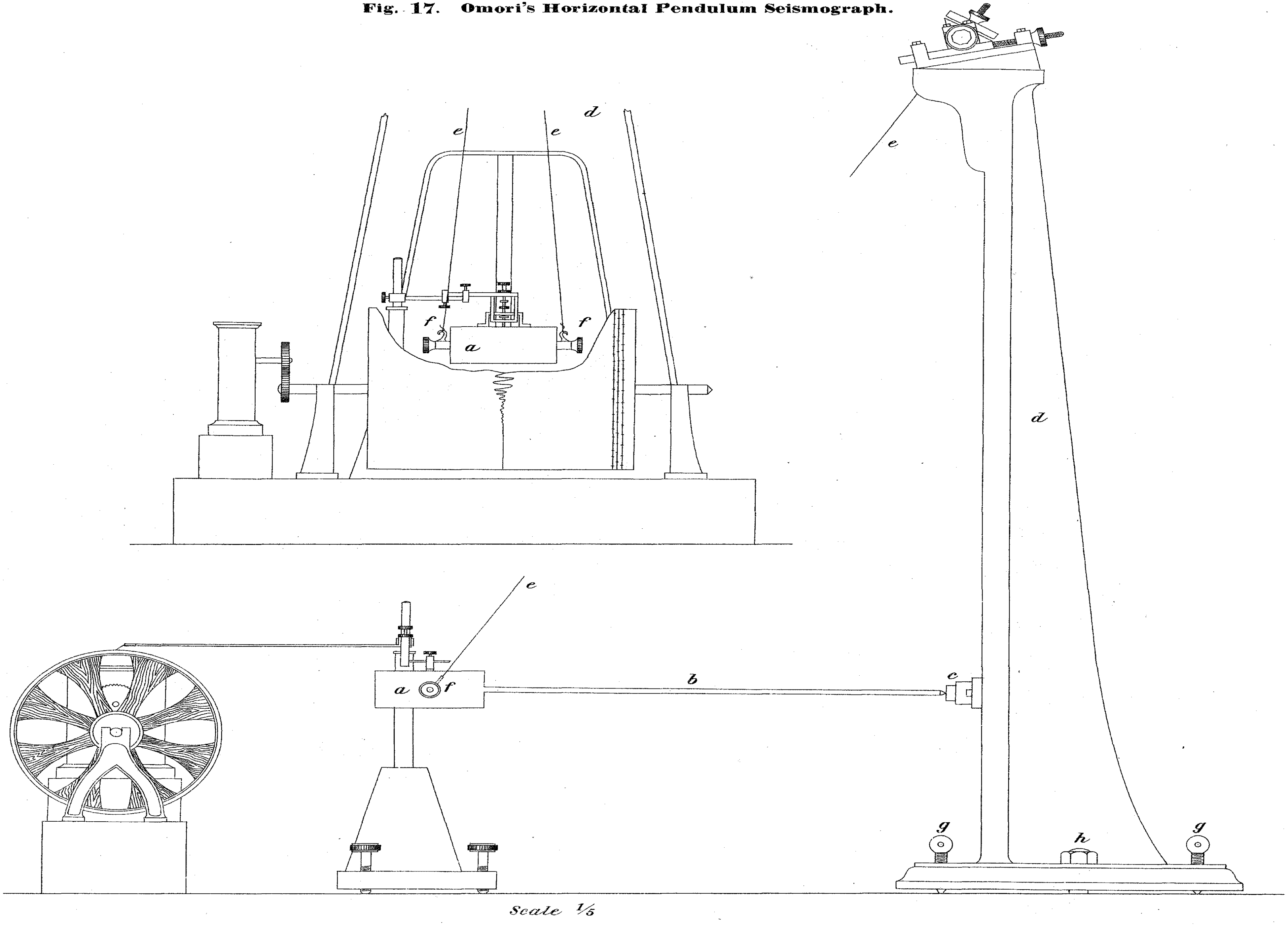
The mechanical starter is used for strong earthquake seismographs, and consists usually of a ball slightly flattened at one point and resting on a platform. When a sufficiently strong shock comes, the ball rolls off the platform, thereby setting free the clockwork. Recently, a very ingenious starter has been devised by Dr. A. Imamura, assistant professor of Seismology, which is described in the E. I. C. Publ., No. 7.

37. The starter sets free at the same time a pendulum which by its ticking marks the intervals of time from the start. In connection with the starter, there is also an arrangement for marking the time of starting on the face of a clock, by means of small projections at the ends of the hour, minute and second hands, tipped with a small piece of sponge dipped in red ink; at the same time as the starting of the clockwork, the face of the clock is jerked forward, comes in contact with the sponge and is marked. The time thus marked will depend of course on the sensibility of the contact-maker and is necessarily not very accurate, so that at present it is not used at the Institute.

A copy of a part of the diagram of the destructive Tōkyō earthquake of June 20th, 1894, taken with Prof. Sekiya's instrument is given in fig. 28.

38. Prof. Gray, formerly of the Kōbu Daigakkō (the Engineering College) suggested a modification of the horizontal pendulum: instead of the bob being supported on a rigid framework, he proposed to substitute a heavy mass suspended by a wire from a point in a fixed post and held out by a rigid strut with one end pivoted on a point directly below the point of suspension, thus forming a *conical pendulum.* This is the form adopted in the Gray-Milne Seismograph described in the Phil. Mag. for April, 1887, and also in the Trans. Seism. Soc., Vol. XII.

Fig. 17. Omori's Horizontal Pendulum Seismograph.



39. *Omori's Horizontal Pendulum Seismograph.* All the instruments so far described, including Prof. Gray's Conical Pendulum instrument, will record ordinary or strong earthquake motions, but fail to give reliable records of very small or slow motions accompanying earthquakes, and of pulsatory oscillations. Prof. Omori has adopted the conical pendulum and has constructed a seismograph, which can be made to give records, not only of earthquakes, both ordinary and strong, but also of very small or slow movements of earth accompanying earthquakes or due to distant earthquakes, of small pulsatory oscillations, and of slow changes of level.

The chief parts of one of these instruments are shown in fig. 17. The bob of the pendulum is a cylinder of thin brass, *a*, filled with lead, and say about 10 kgm. in weight, attached a little above its centre of gravity to a strut, *b*, consisting of an iron tube furnished with a sharp steel point pivoted in a conical steel socket fixed to the stand at *c*. The bob is hung by two fine steel wires, *e*, from a point in the stand directly above the socket, the lower ends of the wires being attached to a pair of hooks *f* pivoted to the bob at the ends of its central diameter normal to the pendulum plane. The attachment of the upper end of the wire to the stand is made by an arrangement, by means of which very delicate adjustments of the pendulum, vertical and horizontal, can be made. The distance between the points of suspension and of support is about 1 metre, while the length of the strut is about 75 cm. The period of the pendulum can be made very long, over 60 sec., if desired, so that the proper motion of the pendulum can be clearly distinguished from the real motion of the earth.

In order to reduce the friction at the attachment of the writing pointer, and between the writing pointer and the record receiver, as much as possible, Prof. Omori has devised a special form of the pointer and a special method of attaching it to the steady point. The writing pointer consists of a small steel axis to which a light lever is attached rigidly; the longer arm is of aluminium, while the shorter arm is of brass and forked. By means of a small counterpoise, the centre of gravity of the whole pointer is made to coincide with the axis. The whole lever is supported by the axis, pivoted between two steel sockets, which is fixed to a stand and can be adjusted in proper position. Between the two limbs of the fork of the shorter arm fits exactly a highly polished steel axis which is a prolongation of the central line of the bob of the pendulum and is pivoted in a frame fixed to the upper end of the bob.

To a small U-shaped frame of brass at the end of the aluminium arm of the pointer, is hinged an exceedingly light writing index made of thin triangular piece cut from a watch spring. The point of the index rests on the record receiver, which is a band of smoked glazed paper, wound round a drum. The drum is turned round by clockwork at any required rate differing according to the particular kind of the earth motion that we wish to observe, say from 3 cm. per minute to 3 cm. per hour; the drum has at the same time a slow motion of translation in the direction of its axis. The record is continuous, differing in this important respect from the instruments previously described; and the rotation of the drum is marked by a time ticker which is in circuit with a chronometer.

Instead of hanging and supporting the pendulum from a strong stand, which is then fixed to the top of a stone or brick column, we may make use of the wall of solid buildings, as has actually been done in the Earthquake-proof House in the University ground. [Art. 108.]

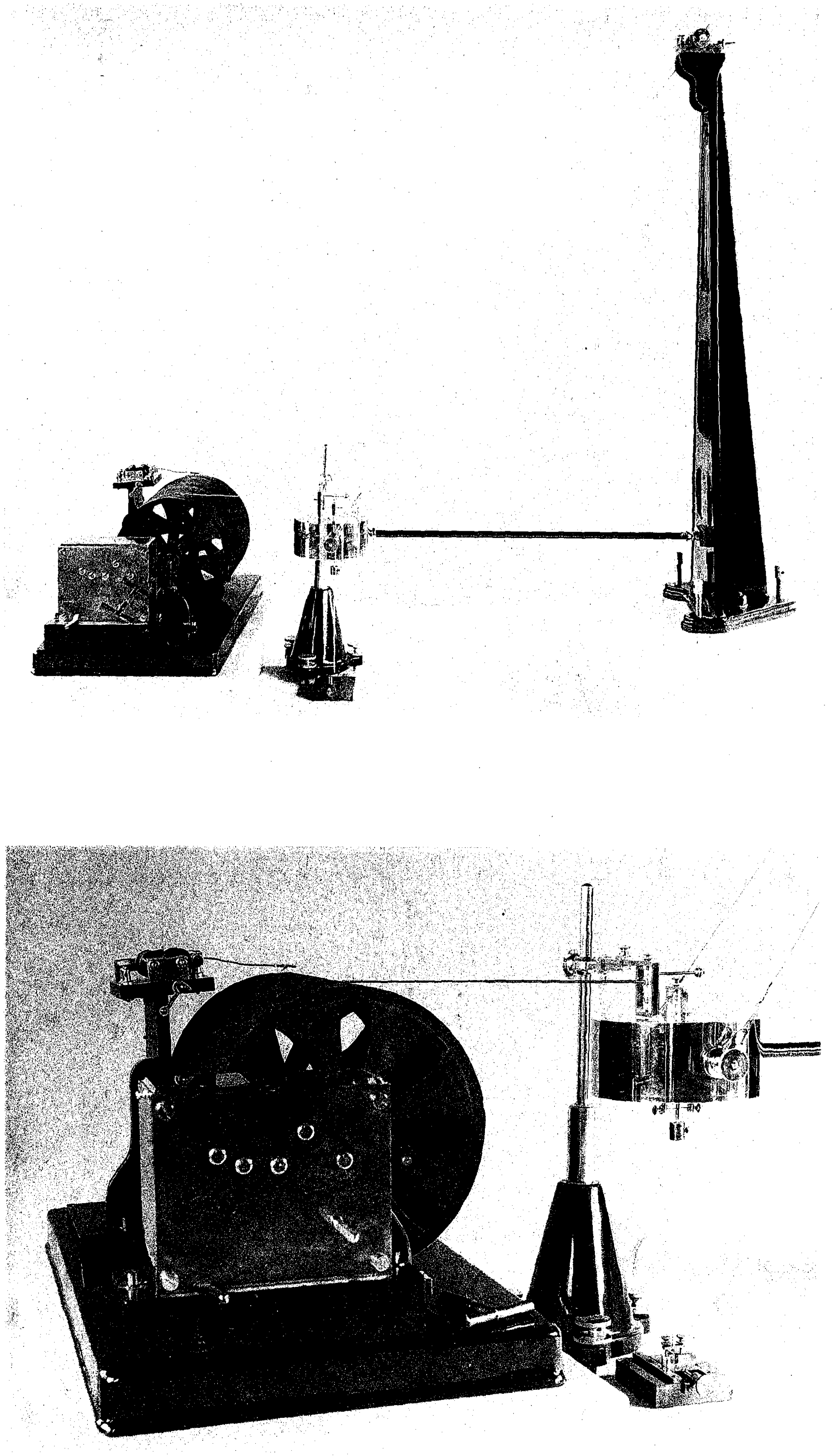


Fig. 18. Omori's Horizontal Pendulum Seismograph.

For a full description of this instrument, see the Jour. Sc. Coll., Vol. XI, or the E. I. C. Publ., Nos. 5 and 12.

40. In the latest form of this instrument, Prof. Omori has made an important modification by introducing the principle of Duplex pendulum. In this form, under the cylindrical bob, there is an inverted pendulum, consisting of a small metallic disk, whose mass is small compared with that of the cylinder, supported on a light aluminium tube pivoted at its lower end in a conical socket and connected with the cylinder at its upper end in such a way that the friction is reduced to a minimum. This arrangement makes the equilibrium of the compound bob still further approximate to the neutral, so that with the vertical distance between the points of suspension and support, and the length of the strut each 1 meter, the period can be made as long as 1 minute, and the multiplication 30 times, without difficulty.[1] [See also fig. 18.]

An instrument of this type having a period of about 30 sec. and a multiplication of 120 times is among the exhibits of the E. I. C. at this Exposition.

41. *Prof. Tanakadate's Parallel Motion Seismograph for Strong Earthquakes.* Prof. West has suggested the use of Watt's parallel motion arrangement as suitable for a seismograph and actually constructed an instrument on this principle.[2]

Some time ago, Prof. Tanakadate has constructed a strong earthquake seismograph by using the same principle in a different way. In this instrument, a heavy mass is pivoted on a rectangular frame which forms the connecting link of a Watt's parallel mo-

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[1] A full description of this instrument has not yet been published, but for an abstract, see Su Buts. K. G., Vol. II, No. 8.

[2] West: Suggestion for a new type of Seismograph; Trans. Seism. Soc., Vol. VI.

tion arrangement. The radius rods are pivoted on to the base plate of the instrument by vertical axes which are slightly inclined towards each other in order to give a small amount of stability to the horizontal motion of the suspended mass. The frame is linked to the radius rods by means of Hooke's joints with the planes of the cross pieces at right angles to each other, so as to make the relative motion of the links kinematically unique, though it deviates from being strictly two dimensional.

A photograph of this instrument with Prof. Tanakadate's Vertical Motion Seismograph is shown in fig. 22 [see Art. 46].

42 *Photographic Record Horizontal Pendulum Seismographs.* In all the instruments described above, the record is taken mechanically, thus introducing friction at several points, although it has been reduced to a very small quantity in Prof. Omori's seismograph. The record may be obtained photographically by throwing the light reflected from the steady point on a sensitized paper; this does not introduce friction like a pointer, but on the other hand, the chief objection to almost every photographic recorder at present in use is the very slow rate of motion of the photographic paper, which renders it unfit for recording short period motion.

The E.I.C. had a Rebeur-Paschwitz horizontal pendulum[1] slightly modified, constructed for it by Messrs. Repsold & Sons, and observations were made with it for some time. At present it is not set up for want of a suitable room.

The Committee has also purchased and set up Prof. Milne's Horizontal Pendulum Seismograph in 1899, in compliance with the request of the British Association for the Advancement of

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[1] For a description of the original pendulum see Nova Acta der Kais. Leopold-Carol. Deutsch. Akademie der Naturforscher, Bd. LX, No. 1., 1892.

Science, forwarded through the British Government, the object being to establish a systematic observation of the motion of the earth's crust with similar instruments all over the world. The instrument is at present housed in a small shed built for it; and the result of the observation is reported to the Seismological Committee of the British Association. An examination of the records taken with this seismograph between July, 1899, and Dec., 1902, by Dr. Imamura in whose charge the observation is placed, is given in the E. I. C. Publ., No. 16.[1]

Instruments for recording the vertical motion.

43. A vertical motion seismograph presents a difficulty not met with in a horizontal motion seismograph, for here we have gravity acting in the direction in which the freedom of motion is to be retained. The first successful attempt made was the Helical Spring Seismograph[2] of Prof. Gray. The essential point of this instrument is a helical spring, supporting a lever which turns about a knife edge at one end, and is weighted at the other end with a lead ring. This arrangement by itself makes the period of oscillation of the mass greater in the ratio of the square roots of the arms of the lever, than if the mass were hung directly from the spring. But Prof. Gray has added an ingenious device by which the equilibrium is made still nearer to the neutral: from the end of the arm is suspended a small trough pivoted and partly filled with mercury. Now if the mass be raised or lowered, the end of the trough is relatively lowered or raised, and the mercury,

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1) Also see E. I. C. Hō., No. 35.

2) Gray: On a Seismograph for recording the Vertical Motion; Trans. Seism. Soc., Vol. III, or the Memoir of the Science Dept, Tōkyō Univ. No. 9.

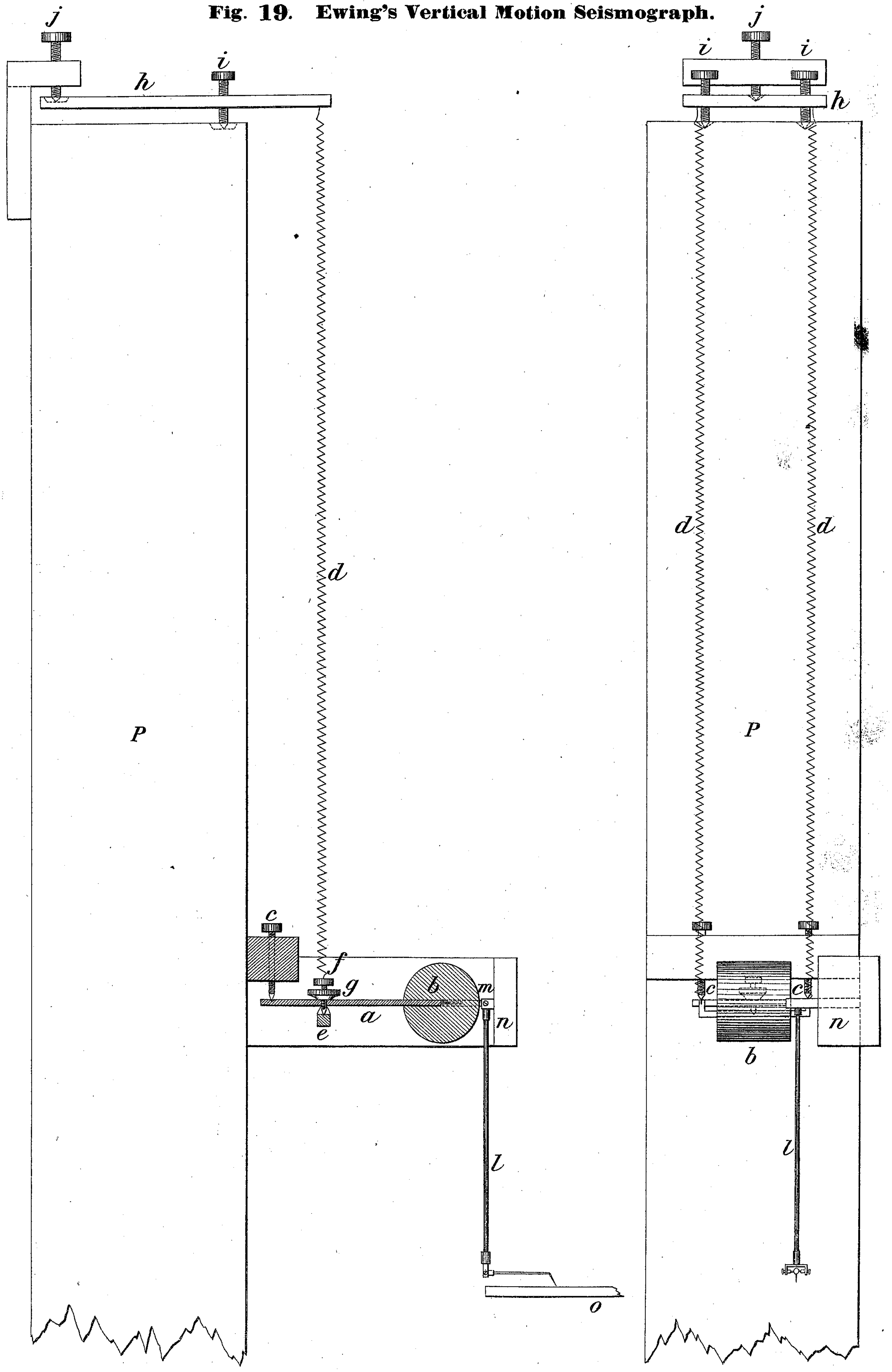
running backwards and forwards tends to increase or diminish the moment about the axis, thus counterbalancing the increase or decrease of the tension of the spring, and so to make the equilibrium neutral.

44. *Ewing's Vertical Motion Seismograph.* Prof. Ewing has adopted Prof. Gray's principle and invented another method of compensation. The chief parts of this seismograph is shown in Fig. 19. The lever is a stout brass plate *a* loaded at the outer edge with a cylinder of lead *b*. A pair of steel points projecting from the fixed pier or post fits into a conical socket and a V slot, cut into the plate near its inner edge, so forming a horizontal axis about which the lever turns. A pair of helical springs *dd*, suspended from a projection in the pier, hangs vertically and is connected at the lower end by a small transverse bar *e*, at the center of which is a conical socket; in this socket, rests the screw *f* projecting downwards from the plate, the length of the projection being adjustable. When the cylinder is lowered or raised, the point of the screw *f*, that is, the point of application of the tension of the spring is moved slightly away from, or towards, the axis about which the lever turns, thus increasing or diminishing the leverage and compensating for the change of tension.

A writing pointer is attached to the bob near its axis, and hanging vertically downwards writes the motion transformed into a horizontal one on a plate or a drum.

45. This instrument, and two bracket seismographs [Art. 35] placed at right angles to one another for the two rectangular components of the horizontal motion, arranged together on a stand so as to write their records on the same drum, form the usual seismographic equipment for local meteorological stations through-

Fig. 19. Ewing's Vertical Motion Seismograph.



out Japan. This I shall call the ordinary Ewing-Gray-Milne seismographs. A photograph of this is shown in fig. 21.

46. *Prof. Tanakadate's Spiral Spring Seismograph.* The construction of this instrument will be seen from fig. 20. The steady point is furnished by the heavy cylinder M, which is supported on two frameworks by having its axis passing through a pair of slots in the arms *L L* of the one, and a pair of holes in the arms *L′L′* of the other: the transverse piece at the other end of each framework forms the axle *A A′*, about which a spiral spring is wound, and which is supported on two vertical pieces *B B′*; the other end of the spring is fixed to the inside of the cylindrical box *D D′* containing the spring. Each spring is wound up so that it will just support one half of the weight of the bob. The bob will thus be in a stable equilibrium, performing small vertical oscillations whose period will depend upon the weight of the mass and the force of restitution of the spring. By attaching a small vertical bar *C C′* to the axle *A A′* of the spring, and putting a small sliding weight *m m′* on it, the system can be brought into a state of neutral equilibrium on adjusting the sliding weight to the proper height. For the full description of this instrument, see E. I. C. Publ. No. 7.

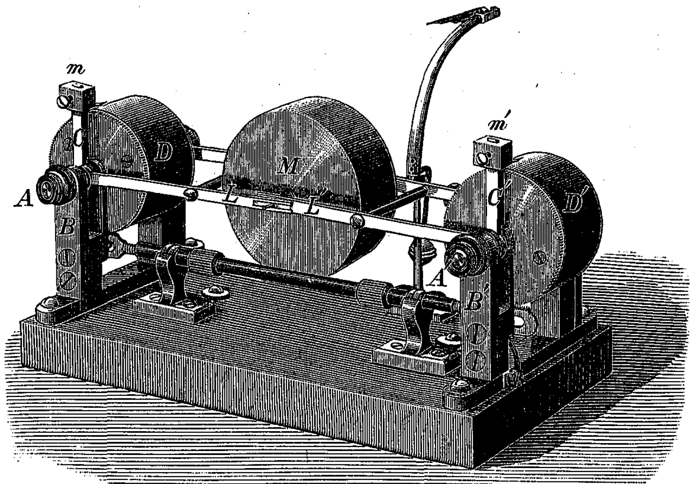


Fig. 20. Tanakadate's Spiral Spring Vertical Motion Seismograph.

The first working instrument of this type was exhibited at the general meeting of the Tōkyō Sugaku-Butsurigakkwai (Mathematical and Physical Society) on June 6th, 1898. It was exhibited at the Paris Exposition of 1901, by the E. I. C. A photograph of this instrument with Prof. Tanakadate's parallel motion seismograph is shown in fig. 22.

47. Thus I have given a short description of seismographical instruments, most of them actually in operation in one or more of the following seismological stations: namely, the laboratory of the Seismological Institute of the Tōkyō Imp. Univ., the Earthquake-proof House of the E. I. C., the Seism. stations of the E. I. C. in direct telegraphic communication with the above laboratory, the Central Meteorological Observatory, the Kyōto Imp. Univ., local meteorological stations, &c. For their full description, you are referred to the publications mentioned.

It will be seen that after all sorts of contrivances had been tried, Prof. Ewing succeeded in constructing a Horizontal Pendulum Seismograph for recording the horizontal motion of the earth particle in two components, and Prof. Gray in applying helical spring to record the vertical motion. Since then, modifications and improvements in details of construction have been introduced, which subsequent experience has shown to be advisable. But the knowledge of the earthquake motion, which was obtained with them, made something more than mere modifications in details necessary for a further advance. Prof. Omori's latest form of the Horizontal or Conical Pendulum Seismograph with continuous mechanical recorder is a very good seismograph, I do not hesitate to say, the best that we have at present: there is plenty of work that can and will be done with it for the present. But there is still room for increasing the neutrality of equilibrium of the pendulum and diminishing friction between the parts; as to the damping

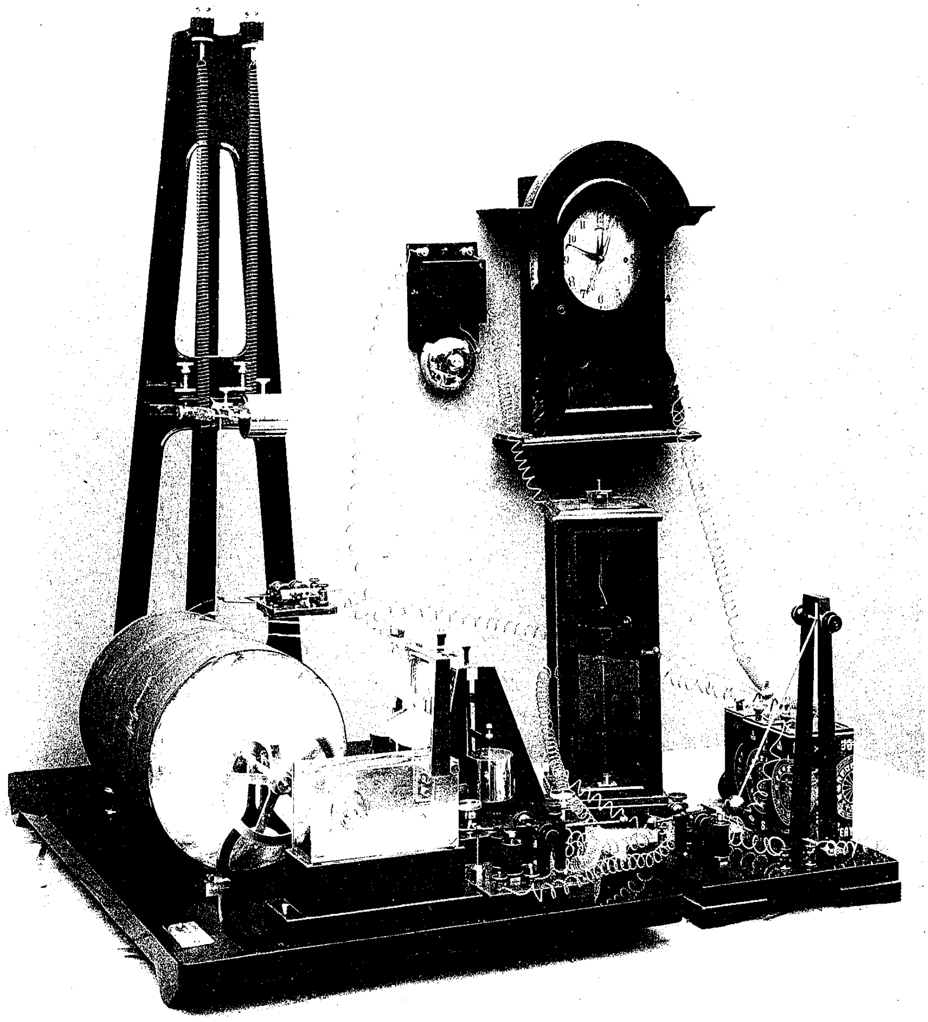


Fig. 21. **Ordinary Ewing-Gray-Milne Seismograph.**

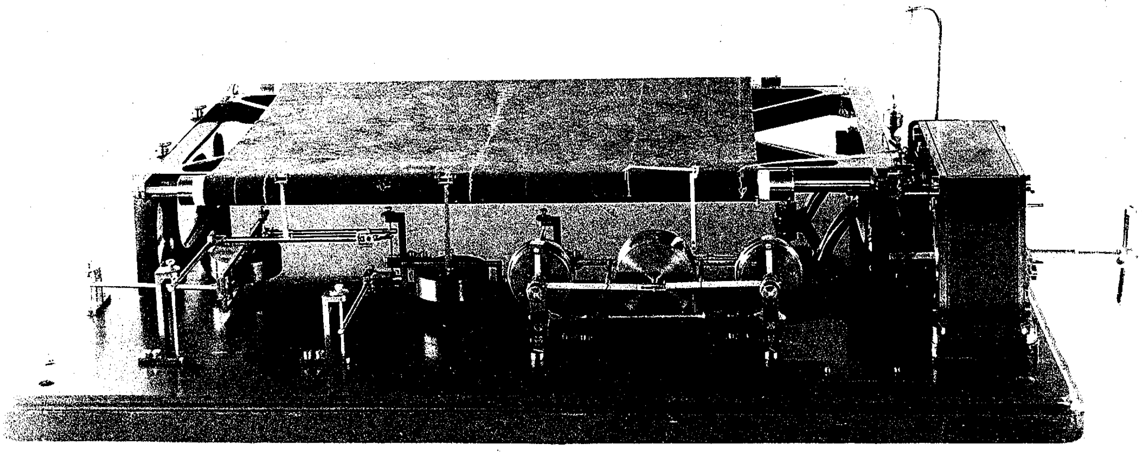


Fig. 22. **Tanakadate's Strong Motion Seismograph.**

of the motion of the pendulum, we are of the opinion, that it is neither necessary nor desirable. A photographic recorder that shall be sensitive enough to enable us to move it with a sufficient speed would be a great improvement.

I proceed now to give some of the most important of the conclusions regarding the nature of vibrations of the earth's crust.

48. The motion of the earth's crust as actually observed, consists in general of several sets of waves of different amplitude and period, which may be partly longitudinal and partly transverse, the amplitude and period ranging within wide limits.

We shall find it convenient to divide the motion into two classes: the *sensible*, or that which can be felt as tremblings or shocks; and the *insensible*, or that which can not be felt. These are sometimes distinguished as *Macro-seismic* and *Micro-seismic*, although these terms have also been employed in a quite different sense by some seismologists. In the former, quick vibrations, i. e. vibrations of short period, coexist with slower vibrations, while in the latter, quick vibrations are either absent or extremely minute. The amplitude of some vibrations in the insensible motion is as large as, or even larger than, that of vibrations in small but sensible local earthquakes; they are insensible only because their period is very long, in comparison with their amplitude, and consequently their acceleration small; in fact, the insensible motion is such because its acceleration is small.

It is evident that observations of the sensible and the insensible motions can not be conveniently combined in one and the same instrument, the chief points of difference in the instruments for measuring them being in the multiplication ratio of the record writer and the rate of motion of the record receiver.

The earth's crust being regarded as an elastic medium through which these waves are propagated, the investigation of these waves, of their mode of propagation, and their behavior under various circumstances is a very important problem of pure Seismology, regarded as a branch of Geophysics. To furnish data for these investigations by accurate determination of the nature of these waves is the province of the observational Seismology.

(B) Sensible or Macro-Seismic Motion.

49. To this class belong motions of earth, known as *Earthquakes* in the ordinary acceptation of the term. They proceed from an origin at a comparatively small distance from the place of observation, say under 1000 km. I shall state briefly some of the results of the observations of these motions, made chiefly with the ordinary (Ewing-Gray-Milne) seismographs [Art. 45].

The Earthquake Motion as observed with the ordinary seismograph begins with vibrations of small amplitude and comparatively short period, these are usually known as the *preliminary tremors*; next come those of larger amplitude, constituting the *Main* and most active part[1]; and finally the earth-

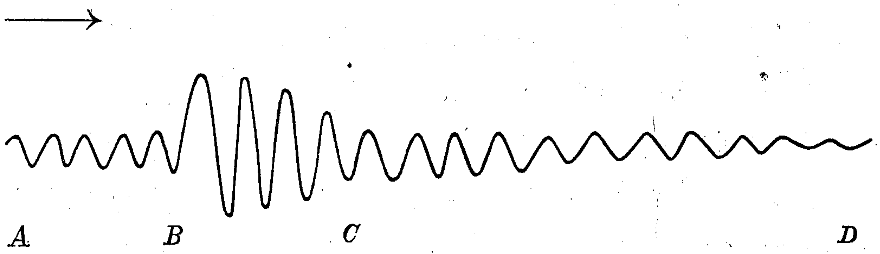


Fig 23. Diagrammatic Representation of the Earthquake Motion.

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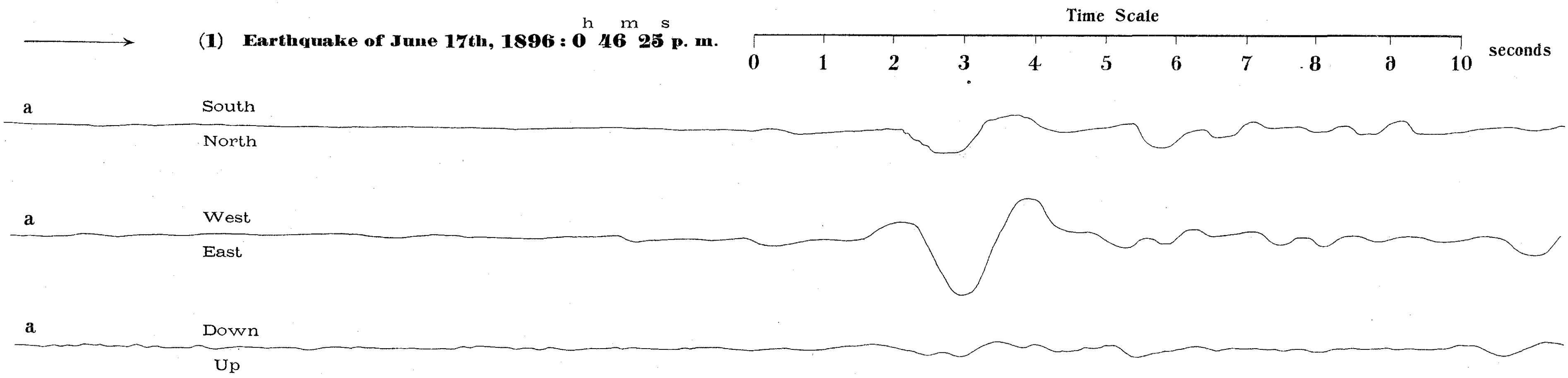
[1] Usually called the "Principal portion."

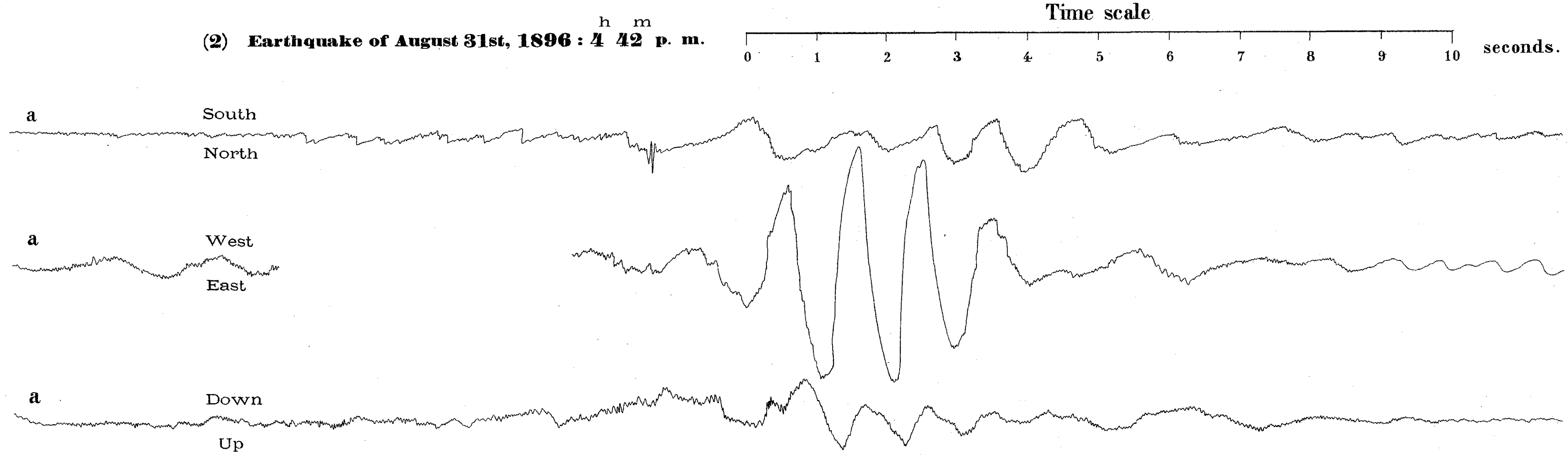
FIG. 24. SEISMOGRAMS OBTAINED AT MIYAKO.

Multiplication of horizontal motion 5 times, that of vertical motion 10 times.
The commencement of motion is marked a.

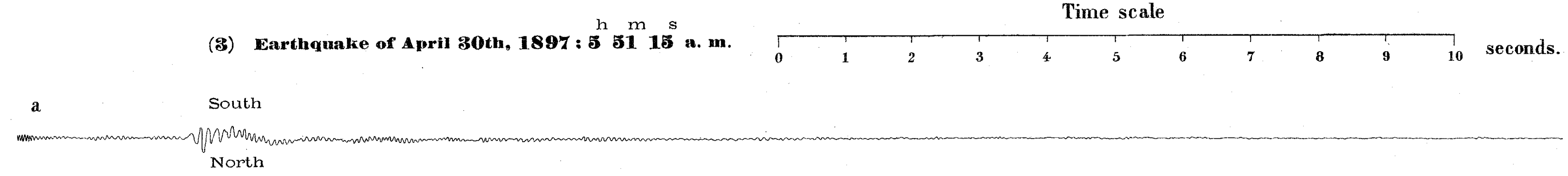
(1) Earthquake of June 17th, 1896 : $0^{\mathrm{h}}\ 46^{\mathrm{m}}\ 25^{\mathrm{s}}$ p. m.



(2) Earthquake of August 31st, 1896 : $4^{\mathrm{h}}\ 42^{\mathrm{m}}$ p. m.



(3) Earthquake of April 30th, 1897 : $5^{\mathrm{h}}\ 51^{\mathrm{m}}\ 15^{\mathrm{s}}$ a. m.



quake ends with feeble vibrations, which I shall call the *Tail*[1] of the earthquake.

In each of these three sections, very small quick vibrations or "*ripples*" are often found superposed on comparatively slower vibrations; the latter constitute the chief element of the earthquake motion and may be termed the "main" vibrations in contradistinction to the ripples; the period[2] of ripples is a mere fraction of a second, while that of the main vibrations is much longer, say between ½ and 2 seconds. The ripples are found more or less in rocky or hard soil district but are almost entirely absent on soft soil. Examples of seismograms are given in fig. 24.

Intensity.

50. In order to indicate the intensity or magnitude of an earthquake, the Central Meteorological Observatory has adopted the following relative scale of intensity for ordinary or non-destructive earthquakes:—

A *slight* shock is one which is very feeble; a *weak* shock is one whose motion is well pronounced but not so severe as to cause general alarm; and, finally, a *strong* shock is one which is sufficiently sharp to produce small cracks in walls, to throw down bottles on a shelf, etc.

For the discussion of the destructive effects of the earthquake motion, we must have an absolute measure of intensity: we may represent the intensity of the earthquake motion by the maximum acceleration, α, of the earth particle: $\alpha=\frac{4\pi^2 a}{T^2}$, in which

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[1] Usually known as the "End Portion."

[2] Throughout this address, the *period* is used in the sense of the complete period, and the *amplitude* of double amplitude.

2a is the amplitude and T the period, of the maximum vibration, supposed to be simple harmonic.

For ordinary non-destructive earthquakes, this maximum acceleration α is small; the shock being a severe one when α reaches a few hundred mm. per sec. per sec.[1]

The acceleration α just sufficiently strong to be perceptible to us without instrumental aid, that is to say, in the slightest sensible motion, is found to be about 17 mm. per sec. per sec.[2]

51. *Maximum movements in different earthquakes.* Fig. 25 shows the relative frequency of the different values of maximum earthquake movements based on the observations of 359 shocks at the Central Meteorological Observatory. It will be seen that the great majority of earthquakes had amplitudes between 0·2 and 0·5 mm. and between 0·6 and 1·0 mm., the numbers of cases corresponding to these two groups being respectively 59 and 19 % of the whole.[3]

Direction of Motion.

52. By the direction of an earthquake is meant the direction of the greatest vibrations, or that of the principal movements during the earthquake, at a given place. In strong earthquakes, the direction of motion often coincides with the line joining the place of observation with the centre of disturbance, as ought to be the case if the principal vibrations in an earthquake be due to longitudinal waves.

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1) For the acceleration in a destructive earthquake see Art. 66.

2) F. Omori: On Earthquake Motions; E. I. C. Hō., No. 41.

3) Loc. cit.

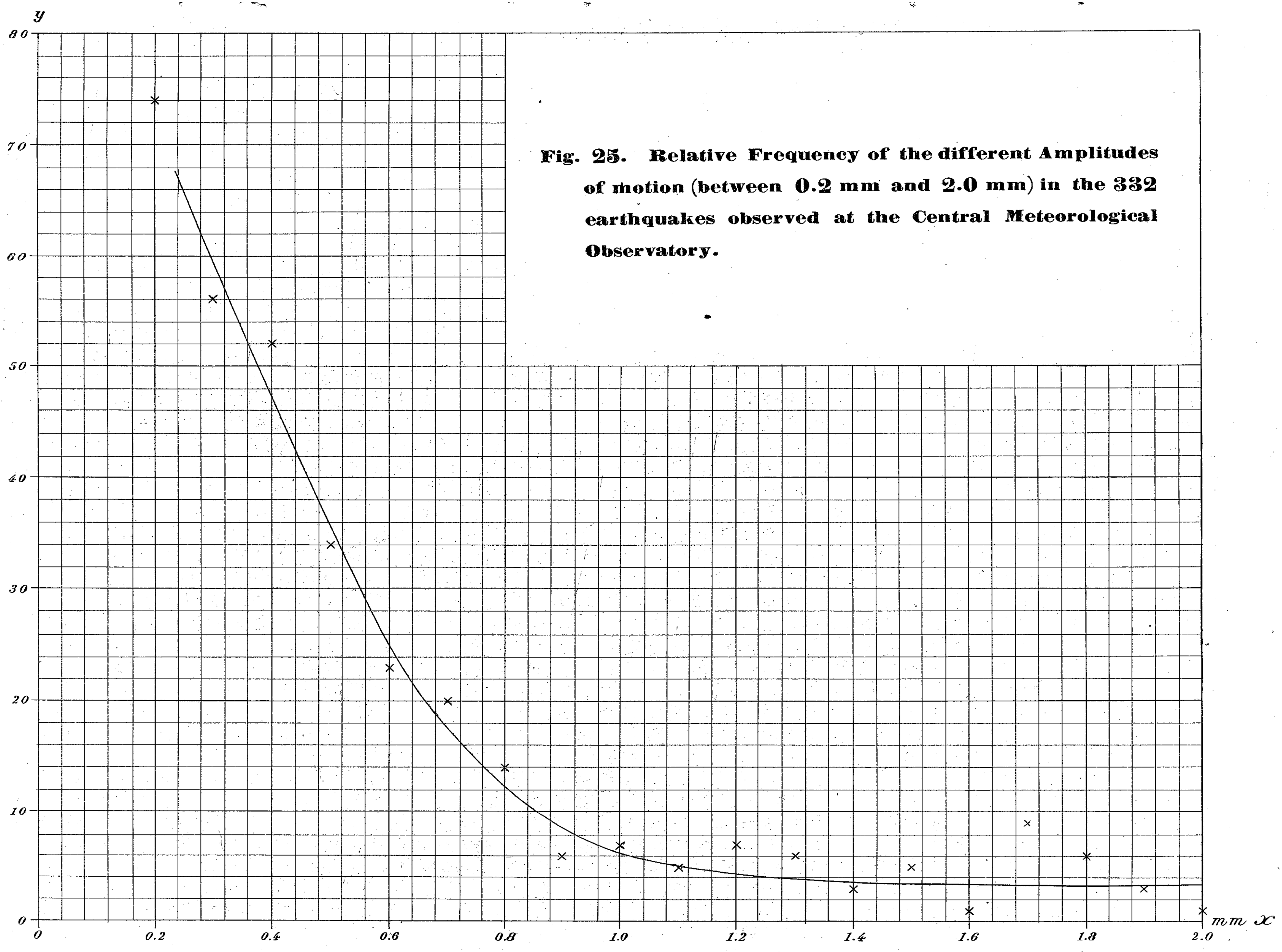

Fig. 25. **Relative Frequency of the different Amplitudes of motion (between 0.2 mm and 2.0 mm) in the 332 earthquakes observed at the Central Meteorological Observatory.**

x=Maximum amplitude (double) of motion in mm.
y=Number of earthquakes whose max. amplitude of motion was x.

Different localities seem to have, in many cases, some prevailing directions of the earthquake motion. Thus, in Tōkyō, the principal directions are E-W and SE-NW [as will be seen from fig. 26 which shows the relative frequency of the different directions of motion of 431 earthquakes observed at the Central Meteorological Observatory during the 13 years between 1885 and 1897.][1] Again, in Miyako, which is situated on the north-eastern coast of the Main Island, the motion in the E-W component is generally much greater than that in the N-S; the direction of the maximum vibrations in the different earthquakes being mostly E-W, ESE-WNW, and ENE-WSW.[2]

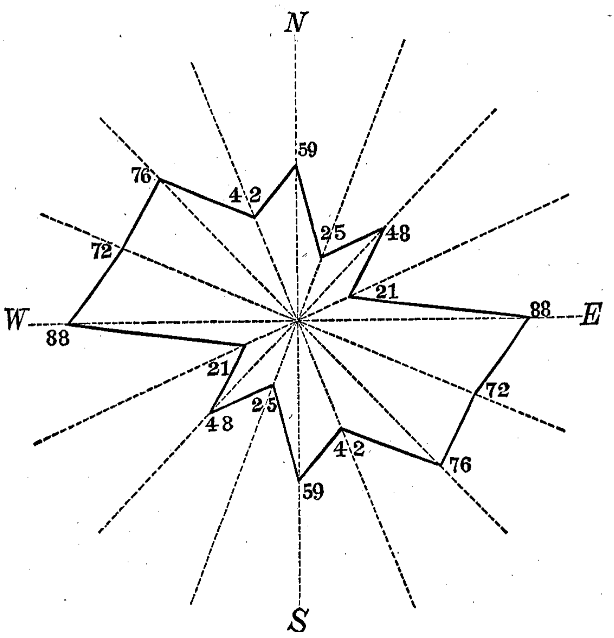

Fig. 26. The Directions of Earthquakes in Tōkyō.

This should be taken into account in choosing the direction of a long building, and in many other ways in practice.

Duration.

53. *The total duration of an earthquake* depends on its

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[1] F. Omori: On Earthquake Motions; E. I. C. Hō., No. 41.

[2] F. Omori and K. Hirata: Earthquake Measurements at Miyako; Jour. Sc. Coll., Vol. XI.

magnitude and on the distance of the observing station from the origin. The relative lengths of the total earthquake duration and of those of the preliminary tremors and the main part will be best seen from the following results deduced from the earthquake measurements at Miyako:[1]—(*a*) Total earthquake duration varied between 8½ and 200 sec., the average value being 72 sec.; (*b*) the duration of the preliminary tremors varied between 0 and 26 sec., the average value being 9½ sec.; (*c*) finally the duration of the main part varied between 0·7 and 26 sec., the average value being 10 sec.

54. *The duration of the preliminary tremors* does not depend on the magnitude of the earthquake but is found to vary with the distance.[2] Thus if y denote the duration of the preliminary tremors of an earthquake at a place, whose distance from the origin of disturbance is x, we have the following empirical equation:—

$$x^{\text{km}} = 7{\cdot}27\, y^{\text{sec}} + 38^{\text{km}}$$

which is to be used for values of x between 100 and 1000 km. [See fig. 27]. This equation is very useful and enables us to estimate, from the diagram at any station by a sufficiently sensitive seismograph, the distance of the origin of a shock. Or, if the seismographic records be simultaneously taken at two or more stations, we can, from the comparison of the durations of the preliminary tremors, easily fix the approximate position of the origin.

55. As to the *duration of the main part in destructive and strong earthquakes*, the result deduced from an examination of

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[1] F. Omori and K. Hirata: Earthquake Measurements at Miyako; Jour. Sc. Coll., Vol. XI.

[2] F. Omori: Note on the Preliminary Tremor of Earthquake Motion; Jour. Sc. Coll., Vol. XI; also E. I. C. Publ., Nos. 5 and 13.

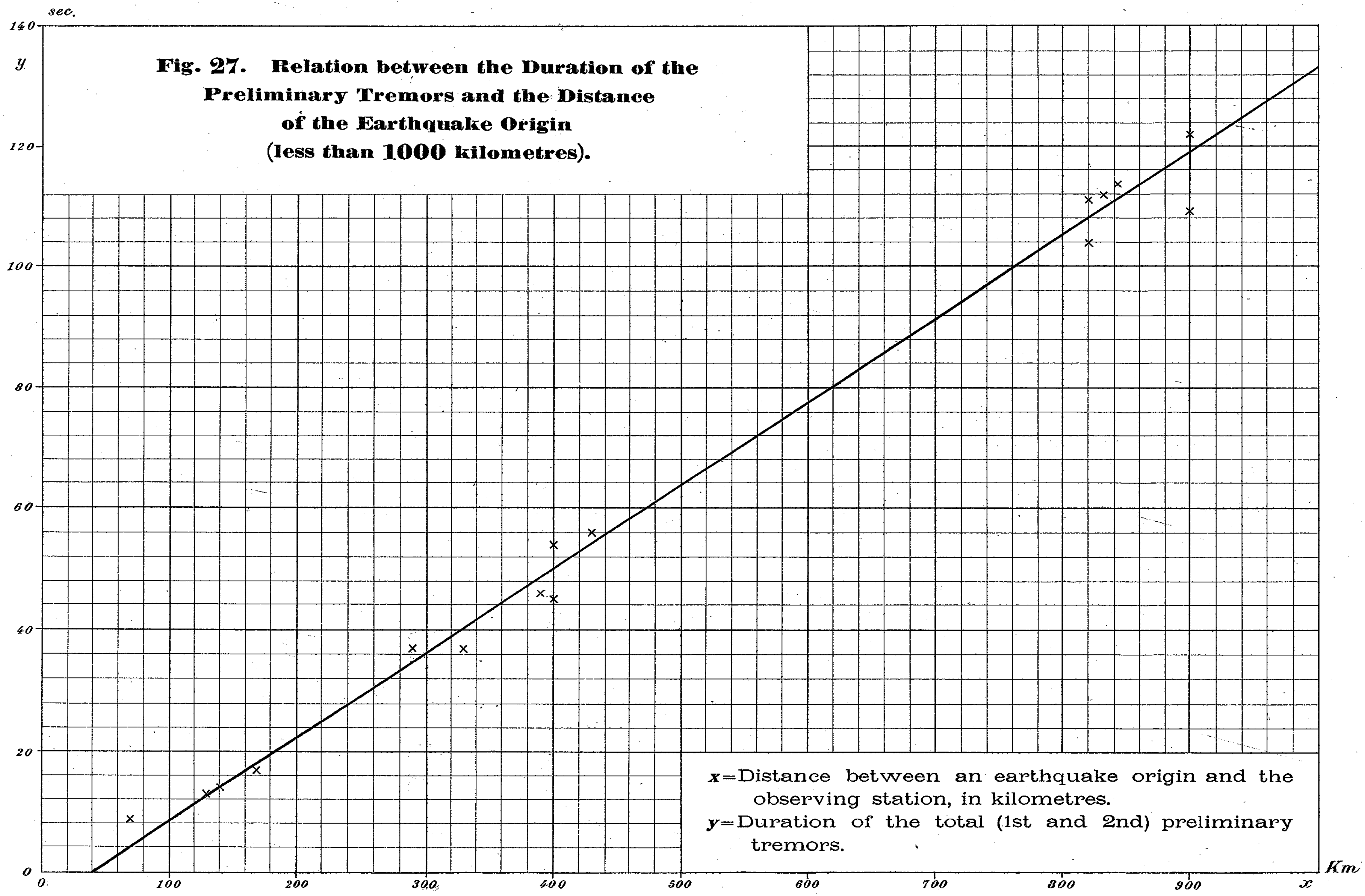

Fig. 27. Relation between the Duration of the Preliminary Tremors and the Distance of the Earthquake Origin (less than 1000 kilometres).

the seismograms obtained in Tōkyō and other places of the Tōkyō earthquake of Oct. 15th, 1884 and twelve other destructive and strong disturbances is as follows:—The two longest were the great Mino-Owari earthquake, 28 sec., and the Riku-U earthquake of 1896, 26 sec.; two others were each 19 sec.; and the remaining nine varied between 4 and 9½ sec.[1]

Period of Vibrations at Miyako.

56. As illustrative of the earthquake motion in a rocky district, we may take the results of observation at the meteorological station of Miyako, which is situated on a small promontary of palæozoic rocks, about 30 m. in height. The periods of vibrations observed at Miyako were as follows:

The period of the maximum horizontal motion varied between 0·53 and 1·7 seconds; *the corresponding period in the vertical motion* varied between 0·53 and 1·7 seconds; the vertical and the horizontal components having, in most cases, the same period.

With regard to the *ripples* the period, which was the same in all the three components varied between 0·04 and 0·12 second. It may be mentioned in this connection that the quickest ripples so far observed were in the case of one of the after-shocks of the great Mino-Owari earthquake registered at the temporary seismological station set up in the village of Midori in the Neo-Valley, the most central part of the meizoseismal zone; the complete period being only about 0·02 second.

I may also remark here that the amplitude of the ripples is

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[1] F. Omori: On Earthquake Motions; E. I. C. Hō., No. 41.

sometimes quite large, the greatest value observed at Miyako being 7·4 mm.

Earthquake Measurements at Hitotsubashi and Hongō.

57. As examples of earthquake measurements in non-rocky districts, we may take those made at Hitotsubashi and Hongō (Seismological Institute), both in Tōkyō. At Hitotsubashi the ground is low and very soft, while at Hongō, it is high and of hard clay.

The average values of the elements of earthquake motion at Hitotsubashi are as follows.[1]

(*a*) *Horizontal Motion*:—

Duration=101 sec.
Maximum amplitude=0·70 mm.
Period of max. motion=0·77 sec.
Maximum acceleration=20·0 mm./sec.^{2}
Average period=0·76 sec.

(*b*) *Vertical motion*:—

Duration=58 sec.
Maximum amplitude=0·22 mm.
Period of max. motion=0·54 sec.
Average period=0·53 sec.

Thus it seems that the mean value of the period of the maximum vibration, both in the horizontal and the vertical component, seems to be practically identical with that of the average period. The case might be somewhat different if we take only strong earthquakes. The horizontal motion lasts twice as long as the

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[1] F. Omori: Macro-seismic Measurement in Tōkyō, II; E. I. C. Publ., No, 11, p. 51.

vertical motion, while the maximum amplitude and period of the former are respectively about 3 and 1·4 times those of the latter.

The period of vibration (horizontal) has no relation at all to the distance of the origin or to the mean radius of the area of disturbance. The conclusion is that the period at Hitotsubashi is essentially characteristic of the locality itself. Such is probably also true of other districts, where the soil is very soft.

At Hitotsubashi ripples do not practically exist, the soil being apparently too soft to admit of the formation of vibrations of a very quick period.

58. *The average values of the duration and the maximum amplitude at Hongō* are as follows:—[1]

Duration of horizontal motion=96 sec.
Maximum horizontal amplitude=0·79 mm.
Duration of vertical motion=51 sec.
Maximum vertical amplitude=0·22 mm.

Thus at Hongō also the horizontal motion lasts twice as long as the vertical; the amplitude of the former being nearly 3½ times that of the latter.

The period of vibrations is not so uniform as at Hitotsubashi, there existing evidently several different sets of waves. Thus, with respect to the maximum horizontal vibrations there are essentially four periods, whose mean values are 0·26, 0·60, 1·25, and 2·6 sec.; the one most frequently occurring being the 2nd one. These four periods are roughly in the ratios of 1:2:4:8. With respect to the mean period of vibrations, there are similarly four periods: 0·22, 0·57, 1·18, and 2·2 sec.

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1) F. Omori: Macro-seismic Measurement in Tōkyō, II; E. I. C. Publ., No. 11, p. 53.

In vertical vibrations, we have four different periods of 0·23, 0·44, 0·63, and 0·91 sec. These four sets of periods are roughly in the ratios of 1:2:3:4.

With regard to the ripples, there are two different periods of 0·20 and 0·47 sec.; the former predominating.

It is to be observed that the two periods of the ripples are practically identical with the two shorter periods of the vertical motion. This seems to indicate that the ripples and the vertical vibrations belong, in some cases, to one and the same kind of waves, which is probably in a part of the character of surface waves.

Comparison of Earthquake Movements on different Soils, etc.

59. *The difference in the earthquake movements according to the nature of the soil* is well exemplified in the results of the observations at the three stations mentioned above. The comparison of the results at Hitotsubashi and Hongō are especially valuable, as here we can compare the measurements of the same earthquakes at the two places.

Prof. Sekiya, who was the first to make investigations relative to the systematic earthquake measurements in Tōkyō,[1] obtained many important results, one of which relates to the comparison of the earthquake motion at Hongō and Hitotsubashi. He found that in hard ground (Hongō) the motion was smaller, the period quicker, and the duration shorter, than in soft soil (Hitotsubashi); their ratios being 1 to 2, 1 to 1·3 and 1 to 1·5 respectively.

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1) S. Sekiya: Earthquake Measurements of recent Years especially relating to Vertical Motion; Jour. Sc. Coll., Vol. II.

The result[2] subsequently obtained by Prof. Omori from a comparison of measurements of identical earthquakes made simultaneously at Hitotsubashi and Hongō was nearly similar to that obtained by Prof. Sekiya; the mean results of the comparison[3] being that the duration at Hitotsubashi was 1·7 times longer than that at Hongo, the maximum motion and the period at the former greater than those at the latter respectively in the ratios of 1·9 and 1·4. Consequently the maximum acceleration at Hitotsubashi is 1·2 times greater than that at Hongō.

The above comparison relates to non-destructive earthquakes. In destructive earthquakes, the period of principal vibrations will not be very quick and consequently will not much differ at Hitotsubashi and Hongō.

60. Loose soft soil and hard compact ground considerably differ in their elastic qualities, but their specific gravities do not much differ from each other. Consequently it is to be expected that the earthquake movements in a loose soft soil will, in general, be slower in period and greater in amplitude than those in a hard compact ground or rocky district.

The dependence of the intensity of earthquake motion on the nature of soil is sometimes very strikingly shown. Thus, for example, on the occasion of the great Mino-Owari earthquake, the shock was very strong in the city of Hikone in the province of Omi, where several houses and temples were entirely overthrown; while on a neighbouring hill the shock was much weaker, even stones lanterns (Japanese lamp posts for gardens) not being overturned.

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[1] Omori: Macroseismic Measurement in Tōkyō; E. I. C. Publ., No. II; or Hō, No. 41.

[2] These results being mean of different set of earthquakes from those in the preceding Arts. are not the same as would be derived from the above.

The effect of earthquake motion will similarly be felt very severely in a valley district, where loose soil is superposed on a hard formation.

61. *Semi-gravity waves.* In destructive earthquakes, the ground surface may, under certain circumstances, be thrown into a species of gravity waves of short wave-length, just in the same way as strong earthquakes cause waves in lakes and seas; the earthquake movements must then be accompanied by a considerable amount of tilting of the ground. This probably accounts for the statement often met with in narratives of earthquakes that the ground was thrown into wavy forms. Especially on the occasion of the Mino-Owari and Shōnai earthquakes of 1891 and 1894, several reliable observers reported having witnessed this phenomenon. Further, in the epicentral districts of these earthquakes, several cases were noticed, in which the surface of the ground was thrown into permanent curved forms. These disturbances, which usually took place on paddy fields or other soft marshy ground, were sometimes limited in area, while in others they consisted of a series of parallel ridges and depressions continuing for several hundred metres. In all the cases, however, the wave-length, that is, the distance between successive ridges or depressions, which in the case of those formed in paddy fields can easily be recognized on account of the ridges projecting out of water, was small and amounted to from 20 to 40 m. Now, as the ground showed these permanent wavy deformations after the earthquakes, we may reasonably suppose that wavy movements of the ground were executed during the earthquakes.[1]

62 *Comparison of the Earthquake Motion above*

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[1] F. Omori: On Seismic Instruments; Verh. d. 1. intern. Erdbeben Conferenz zu Strassburg, 1901.

and below the Ground Level. From a practical point of view, with reference to the building of houses, it is interesting to investigate the shaking in pits, or excavations which might be made for foundations. Such a measurement was first undertaken by Prof. Milne, who found that the motion in a pit 10 feet deep was, in one case, much smaller than on the surface.[1] The experiments subsequently made by Professors Sekiya and Ōmori in a pit 18 feet deep, at Hongō, seem to show that in severe earthquakes there may be less destructive effects in deep pits than on the free surface.[2]

63. *Marginal vibrations.* At the edge of a steep bank or slope, the motion is intensified on account of want of side support. To this phenomenon of "*Marginal Vibrations*" is due the formation of cracks along river banks and the occurrence (during earthquakes) of landslips from mountain sides.

To observe the effects of marginal vibrations, late Prof. Sekiya placed a seismograph at the steep edge of a hill in Tōkyō, 38 feet in height, and another similar instrument at its foot. The motions at these two levels were found to be in the mean ratio of 2 : 1.[3]

Earthquake Sounds.

64. In many cases, a rumbling sound like that of a distant thunder, or a rushing sound like a blast of wind is heard just before, or simultaneously with, the arrival of the tremblings of the ground,

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[1] Milne: On a Seismic Survey made in Tōkyō in 1884 and 1885; Trans. Seis. Soc., Vol. X.

[2] Sekiya and Omori: Comparison of Earthquake Measurements made in a Pit and on the Surface Ground; Jour. Sc. Coll., Vol. IV.

[3] Sekiya: The Severe Japan Earthquake of the 15th of January, 1887; Trans. Seis. Soc., Vol. XI, p. 87.

when the origin of the disturbance is near to the observer. These sound phenomena seem to be of frequent occurrence in a rocky district, but very rare at places situated in plains, like Tōkyō. They have been attributed to various causes by different writers; among others, Prof. Knott thinks,[1] that "they are to be traced to the rapid vertical vibrations of the ground, so rapid as to be inappreciable on our seismographs." It seems very probable, that they are due to the ripples whose period is very short as already mentioned.

The subject requires further study.

Seismic Triangulation.[2]

65. *The velocity of propagation of the ordinary earthquake waves* has been determined with a great accuracy by the E. I. C., which instituted in 1894, at the suggestion of Professors Sekiya and Omori, a system of seismic triangulation, consisting of four stations provided with exactly similar Ewing seismographs connected by a telegraphic wire. The distance between the four stations varied from 2·29 km. to 10·86 km., the four instruments being simultaneously started at the time of an earthquake, and time marks being sent through the wire every second by means of a chronometer. The velocity of propagation was determined by identifying certain particular well defined vibrations in the seismograms, and finding the time differences of their arrival at the different stations. The result, deduced by Dr. Imamura, who has been carrying on the observation since 1895, was

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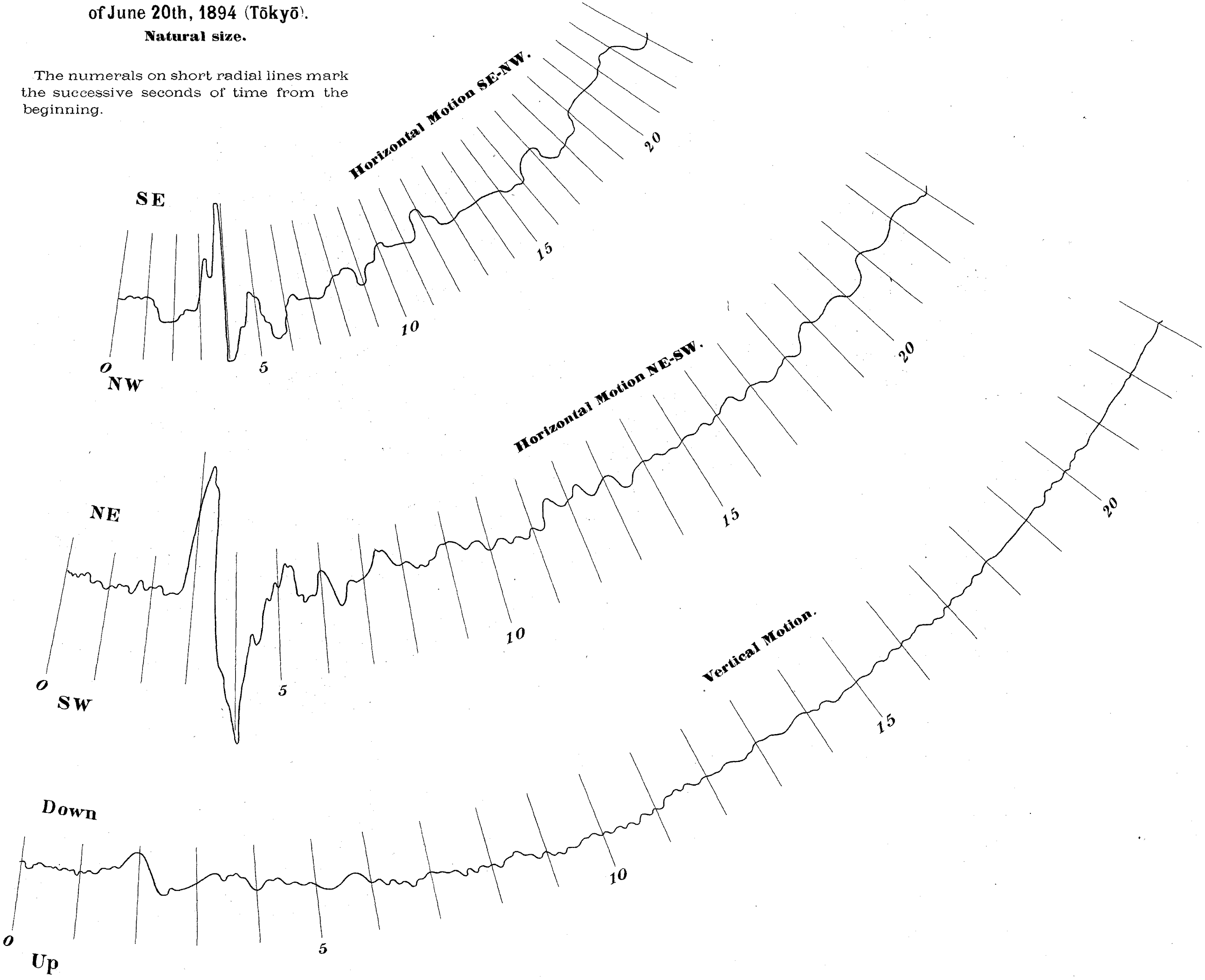
[1] Knott: Earthquakes and Earthquake Sounds; Trans. Seism. Soc., Vol. XII.

[2] F. Omori: Preliminany Report on the Seismic Triangulation; E. I. C. Hō., No. 21. A. Imamura: Seismic Triangulation in Tōkyō; E. I. C. Publ., No. 7.

Fig. 28. Part of the Diagram of the Destructive Earthquake of June 20th, 1894 (Tōkyō).

Natural size.

The numerals on short radial lines mark the successive seconds of time from the beginning.



$$V=3{\cdot}28^{km}\pm0{\cdot}05^{km}.$$

V thus may be taken as 3·3 km. per second.

When the differences of times of arrival of the earthquake motion proceeding from a near origin at the different stations of the seismic triangulation are accurately determined, we can approximately calculate the depth of the focus; the position of the epicentre and the velocity of propagation (=3·3 km. per sec.) being known. In this way, the depths of the centres of the earthquakes on Nov. 30th, 1894 and July 25th, 1898, which were felt in Tōkyō with moderate intensity and whose origins were situated in Tōkyō Bay, were found to be about 60 and 40 km. respectively.

With respect to the velocity of propagation of earthquake waves, I shall have more to say when I come to the observation of the insensible motion.

The Severe Tōkyō Earthquake of June 20, 1894.

66. The earthquake of June 20th, 1894 was the most violent that has shaken Tōkyō since the well known great earthquake of 1855. No house was absolutely destroyed, but in the lower parts of Tōkyō many brick buildings received severe damage, and large number of chimneys was thrown down. The diagram of the earthquake was taken by a strong motion seismograph set up in the Seismological Institute, this being the first time that a clear instrumental record of a destructive earthquake has ever been taken [see fig. 28.] The elements of motion were as follows:—Maximum horizontal motion=73 mm., direction S 70° W, Period=1·8 sec., maximum acceleration=444 mm. per sec. per sec. Maximum vertical motion=10 mm. Prof. Omori remarks that "The character of the earthquake motion was very simple, the preliminary tremors 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 earthquarkes, there is no single prominent displacement, the motion consisting of a great number of vibrations of nearly equal amplitude.''[1]

(C) Insensible or Micro-Seismic Motion.

67. The insensible movements of the ground may be divided into two kinds, according as they are or are not of the earthquake origin. The vibrations not of the earthquake origin have been called Pulsatory Oscillations, while the others are those due to distant earthquakes (very distant and strong, or comparatively near and slight).

Pulsatory Oscillations.

68. The Pulsatory Oscillations are slow pulse-like movements of small amplitude [see fig. 29]. In some pronounced storms of pulsatory oscillations, the motion was quite as large as in small earthquakes; the maximum amplitude in each component being sometimes nearly 0·2 mm. Again, the horizontal motion is, in general, much greater than the vertical; although in some cases, the latter is very marked and nearly equal to the former.

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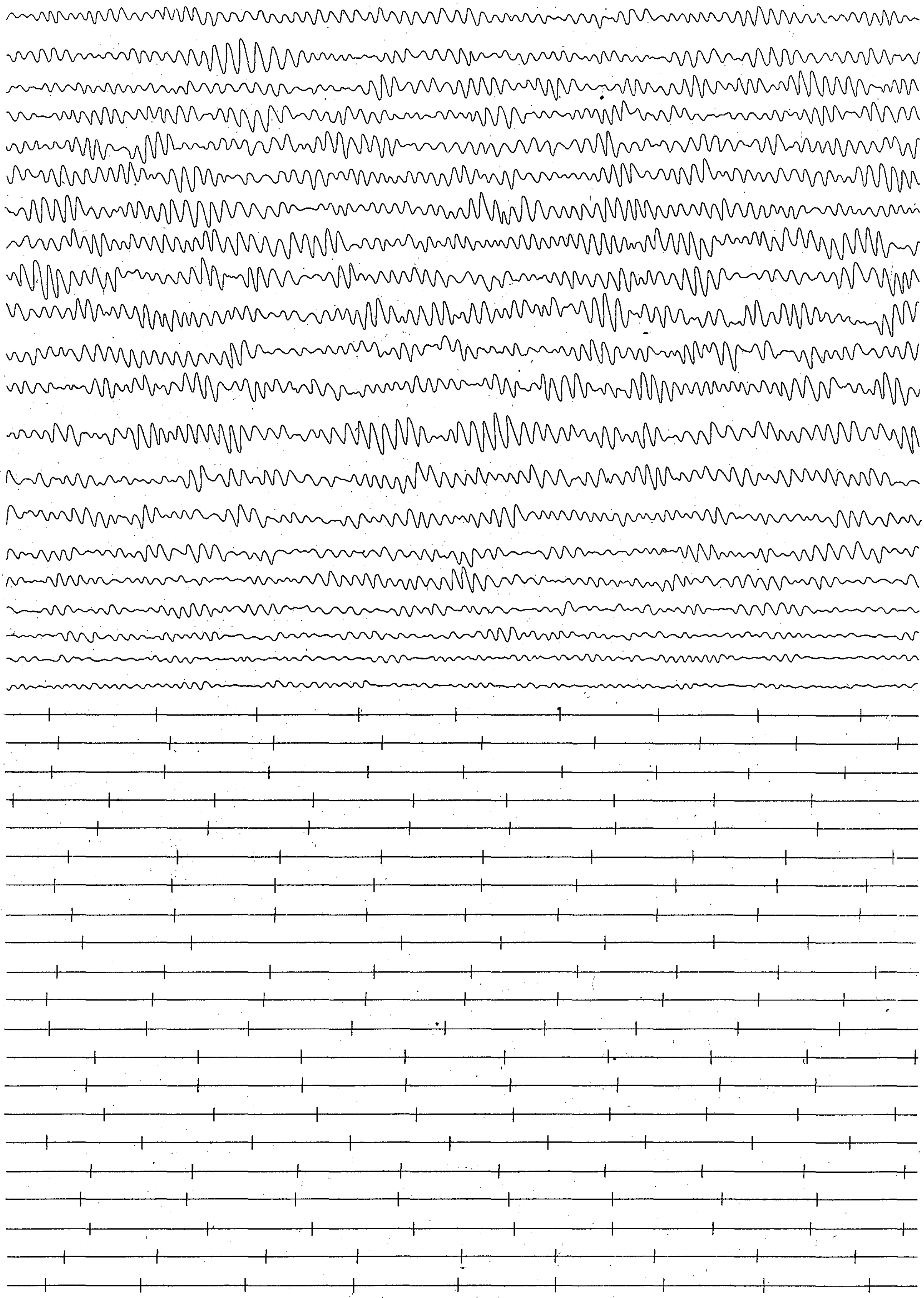
[1] Omori : Note on the Tōkyō Earthquake of June 20th, 1894 ; E. I. C. Publ., No. 4, p. 27.

Fig. 29. **Part of the Diagram of Pulsatory Oscillation Storm on Nov. 17th-18th, 1900.**
(EW Component)
Multiplication 10 times.



Time: 1 tick-interval=1 minute.

The wave-length of pulsatory oscilations seems to be much longer than those of the quick-period vibrations which constitute the ordinary seismic shocks.

The amplitude and period do not vary within a small area, such as Tōkyō. When considered, however, with respect to widely distant localities, there is a great difference in the frequency as well as the intensity of these movements. Thus in Tōkyō, Osaka, and Mizusawa, pulsatory oscillations occur very often and have not seldom quite a large amplitude, all these places being situated on plains of quaternary formation. On the other hand, the horizontal pendulum observations at Miyako meteorological station, Arima and Kyōto Imperial University show very few and slight traces of pulsatory oscillations. The three last named stations are situated on a small promontory of paleozoic formation among granite mountains, and in a valley surrounded by mountains.

As stated before, the period of pulsatory oscillations varies little, and remains generally constant for several successive hours, it may hence be supposed that these movements represent the proper vibrations of certain portions of the earth's crust, such for instance as the plain of Musashi in which Tōkyō is situated. In fact, there is no reason to suppose that the ground, when not disturbed by earthquakes, is perfectly at rest: on the contrary, it would be more general to assume that the different portions of the earth's crust are continually executing greater or less movements of some sort; and the periods of some of these vibrations ought to be determinable in each case from the geotectonic circumstances of the ground.

A careful examination of the horizontal pendulum diagrams obtained in Tōkyō shows that the pulsatory oscillations consist, in most cases, essentially of the vibrations with a period of about 4 sec., more or less mixed up with those of a period of about 8 sec.

The vibrations of 4 seconds period occur very frequently, but cases are not wanting, where the vibrations of the 8 seconds period predominate almost exclusively. Again there are sometimes cases, in which the two kinds of vibrations occur in different parts of one and the same diagram. Thus, in 41 out of the 46 cases of storms of pulsatory oscillations in 1900, the average period varied between 3·4 and 5·7 sec., giving a mean value of 4·4 sec. ($=Q_1$). In the remaining five cases, the average period varied between 7·1 and 9·3 sec., giving a mean value of 8·0 sec. ($=Q_2$): large pulsatory movements at the time of very deep cyclones having generally the 8 seconds period. Some of the cases, in which the period is between 4 and 8 seconds, are probably produced by the mixing together of the two series of movements. We may perhaps assume that the 8 seconds period vibration constitutes the fundamental oscillation proper to the Tōkyō plain, the 4 seconds period vibration being one of its harmonics.[1]

The period of pulsatory oscillations at Osaka[1] varies between 3·1 and 6·9 sec.; the majority being between 4 and 5·9 sec. The total average value of the period comes out to be 5·1 sec., which is approximatly equal to that most frequently occurring in Tōkyō, denoted by Q_1 above.[2]

69. Pulsatory oscillations generally accompany low barometric pressure; the effect of a very deep cyclone being already sensible at a distance of some thousand kilometres. In a few cases, however, pronounced storms of pulsatory

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[1] F. Ōmori: Horizontal Pendulum Observation of Earthquakes at Hitotsubashi (Tōkyō), 1900; E. I. C. Publ., No. 13, pp. 81–86.

[2] F. Ōmori: On Pulsatory Oscillations at Tōkyō and Osaka; Chishitsugaku Zasshi, No. 125, 1904.

oscillations occurred on days when very quiet weather prevailed all over Japan.

In Tōkyō, earthquakes rarely occur while pulsatory oscillations are going on actively. On the other hand, there are often local shocks when these oscillations come to a state of minimum activity. Prof. Omori, by observing the records of pulsatory oscillations, has been able, on several occasions, to predict the occurrence of an earthquake within some 10 or 12 hours.

Observation of Distant Earthquakes in Tōkyō.

70. From the observations made in Tōkyō of insensible motion due to distant earthquakes, made with Prof. Omori's Horizontal Pendulum Seismographs, many important results have been obtained, of which I proceed to give a very brief summary.

71. A careful examination of seismograms shows that the earthquake motion consists generally of several sections, in each of which the period remains essentially constant, while the amplitude is also on the whole constant, except for the occurrence of maximum and minimum groups.

The successive sections of the earthquake motion, illustrated in fig. 30, are as follows:—

The *1st Section*, in which we have vibrations of small amplitude and comparatively short period;

The *2nd Section*, having vibrations of somewhat larger amplitude, and often marked by the appearance of slow vibrations, superposed on the others;

The *3rd Section*, consisting of a few slow vibrations;

The *4th Section*, consisting of vibrations somewhat quicker than in the 3rd section, and of very large amplitude;

The *5th Section*, of vibrations of much shorter period than in the 3rd and 4th sections, and of large amplitude; followed by others of smaller amplitude, which may be called respectively

The *6th, 7th, 8th, &c. Sections.* The 3rd and following sections constitute the main part of the earthquake motion. And finally,

The *Tail*, being the feeble finishing part of the earthquake motion.

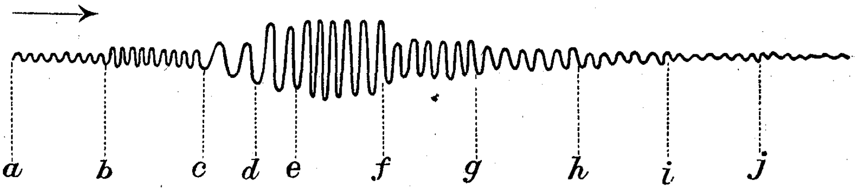


Fig. 30. **Diagrammatic Representation of the Earthquake Motion proceeding from a Distant Origin.**

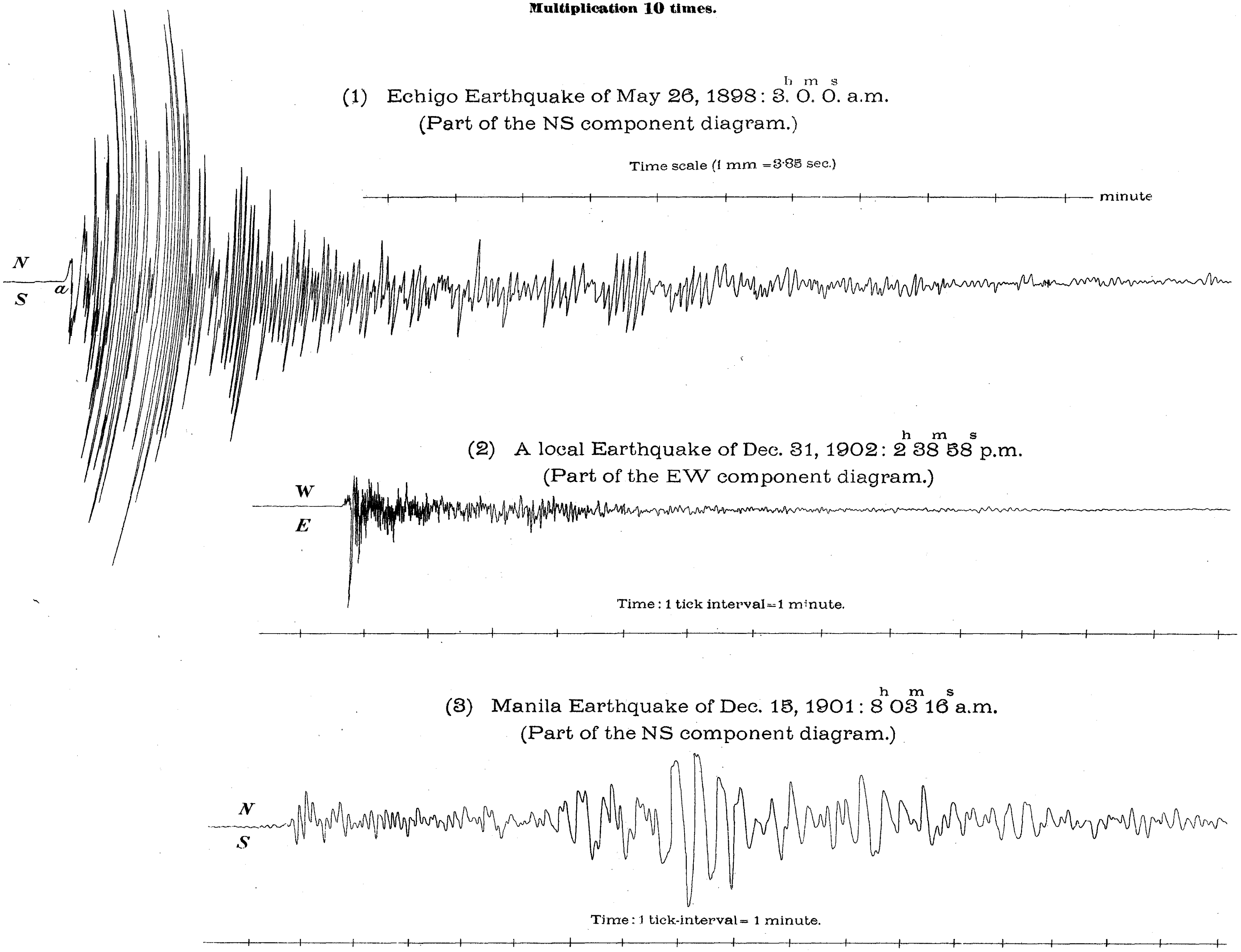
ab	........1st Section, or 1st Preliminary Tremors.		
bc	........2nd Section, or 2nd Preliminary Tremors.		
cd	........3rd Section	Main Part, or	1st Phase of the Principal Portion.
de	........4th Section		2nd " " " " "
ef	........5th Section		3rd " " " " "
fg	........6th Section		4th " " " " "
....			....
j	...........Tail, or End Portion.		

The 1st and 2nd sections are usually known as the *1st* and *2nd preliminary tremors*, the 3rd, 4th, 5th, &c. sections as the *1st, 2nd, 3rd, &c. phases of the principal portion*; and the tail as the *end portion*.

In earthquakes of near origin, the motion is, on account of the existence of quick sensible vibrations, much more complex than

FIG. 31. SEISMOGRAMS OBTAINED AT HONGŌ, TŌKYŌ.

Multiplication 10 times.



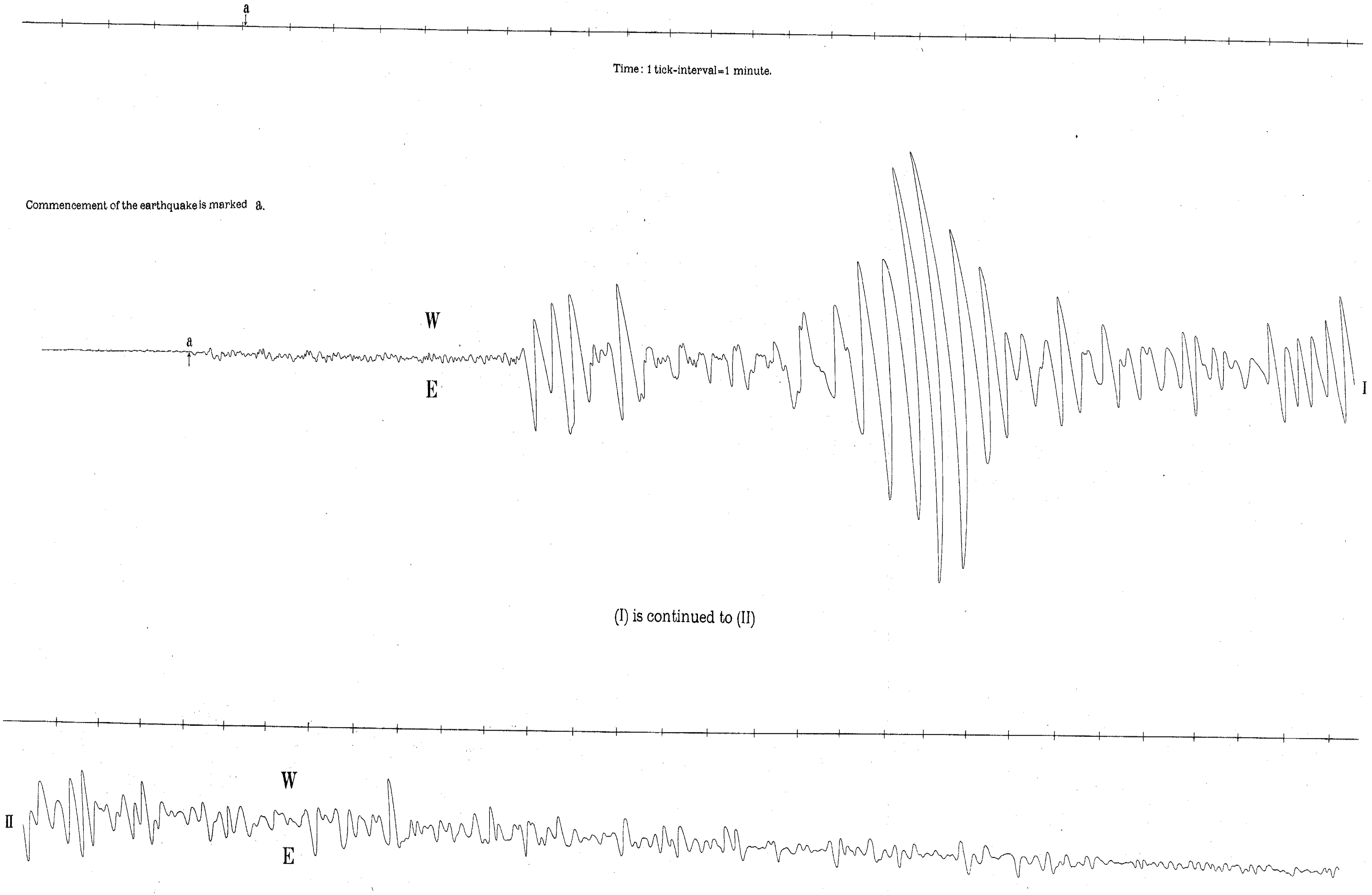
(1) Echigo Earthquake of May 26, 1898: $\overset{h}{3}.\,\overset{m}{0}.\,\overset{s}{0}.$ a.m.
(Part of the NS component diagram.)

(2) A local Earthquake of Dec. 31, 1902: $\overset{h}{2}\;\overset{m}{38}\;\overset{s}{58}$ p.m.
(Part of the EW component diagram.)

(3) Manila Earthquake of Dec. 15, 1901: $\overset{h}{8}\;\overset{m}{03}\;\overset{s}{16}$ a.m.
(Part of the NS component diagram.)

FIG. 32. ALASKA EARTHQUAKE OF SEPTEMBER 11, 1899: $6^{h}\ 50^{m}\ 58^{s}$ A.M., OBSERVED IN TŌKYŌ.

(**Part of the EW component diagram.**) **Multiplication 10 times.**



Time: 1 tick-interval=1 minute.

Commencement of the earthquake is marked a.

(I) is continued to (II)

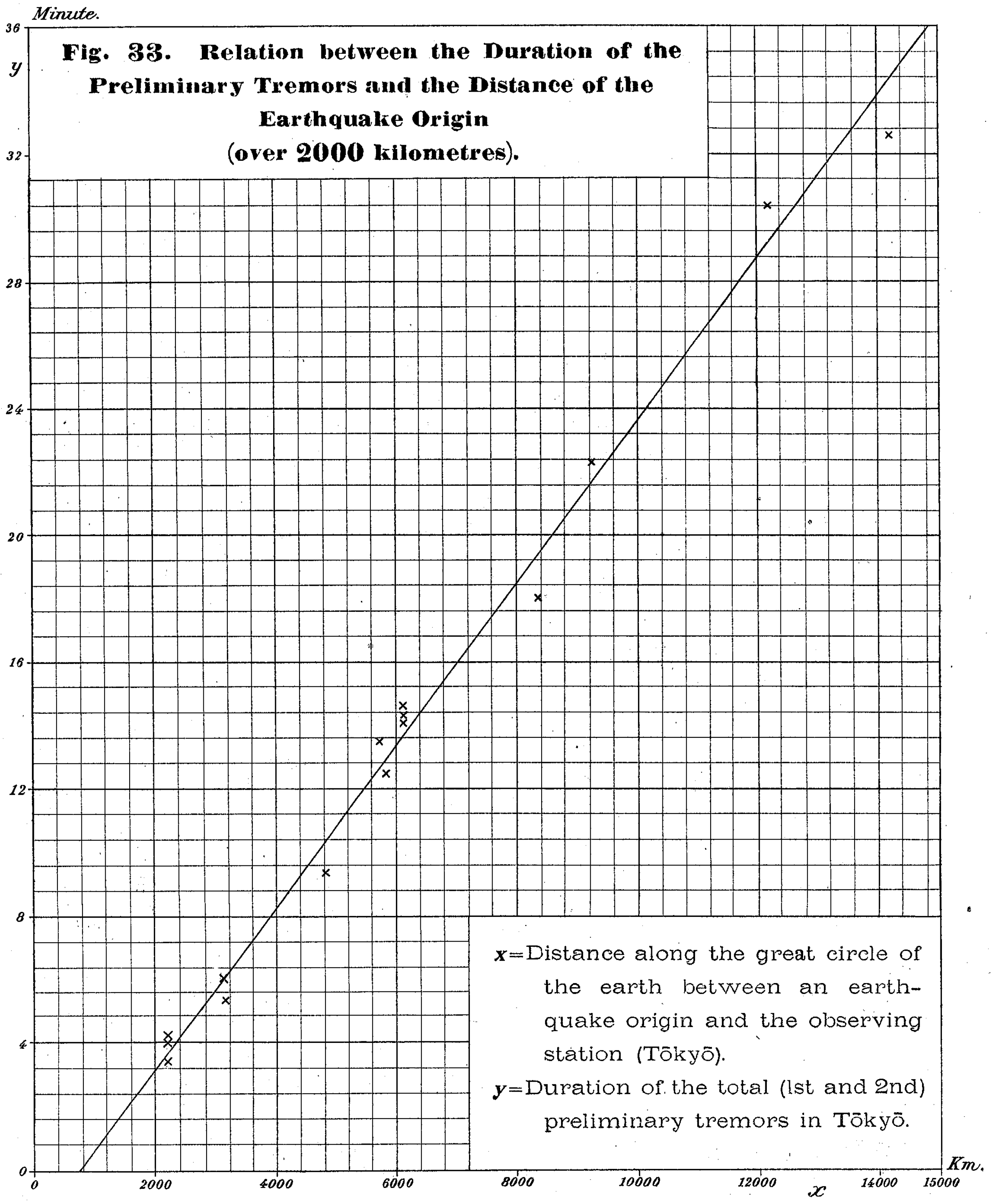
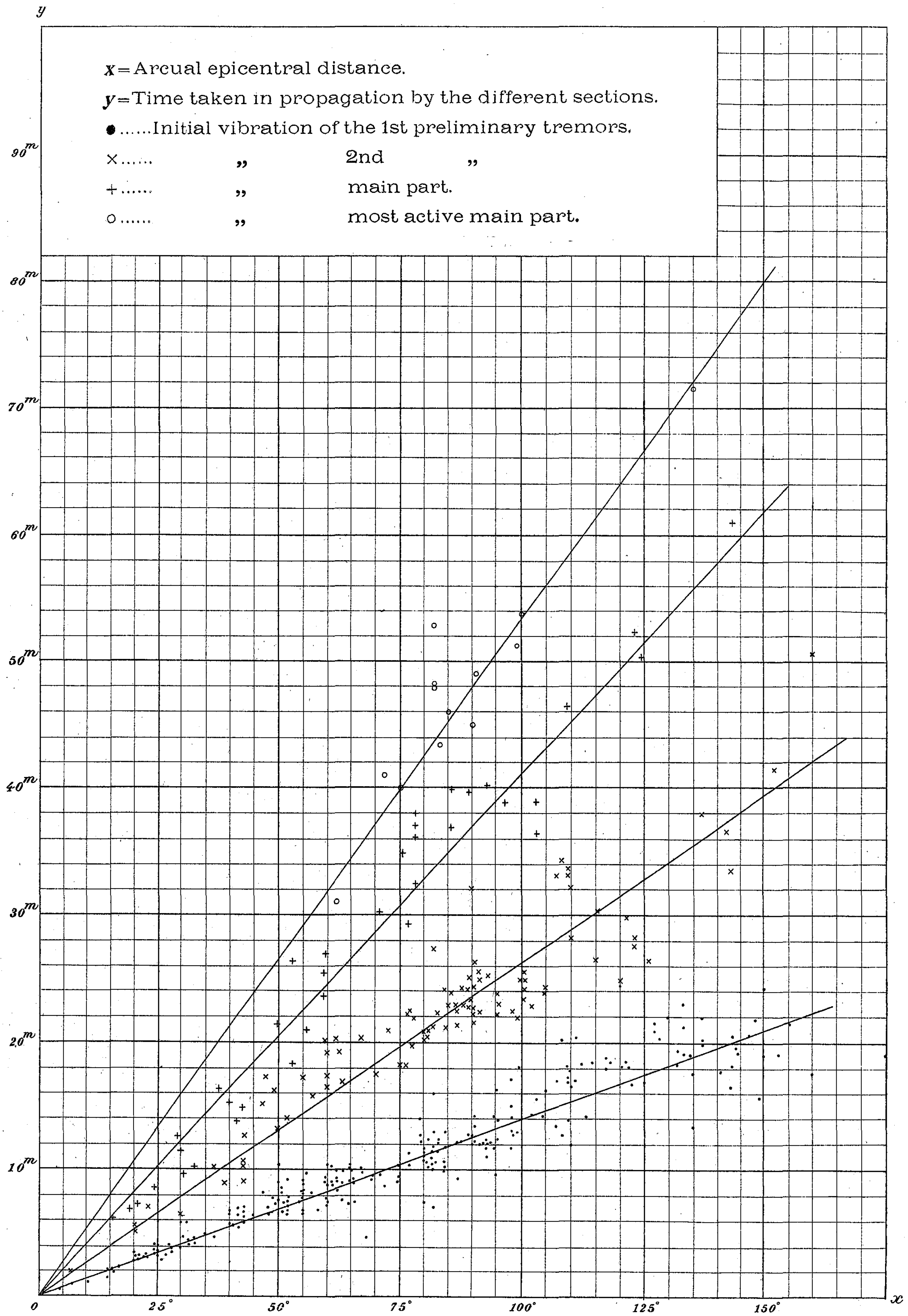


Fig. 33. Relation between the Duration of the Preliminary Tremors and the Distance of the Earthquake Origin (over 2000 kilometres).

x=Distance along the great circle of the earth between an earthquake origin and the observing station (Tōkyō).

y=Duration of the total (1st and 2nd) preliminary tremors in Tōkyō.

Fig. 34. Relation between Arcual Epicentral Distance and the Time taken in Propagation by the different Sections of the Earthquake Motion.



in distant earthquakes. I have already mentioned [Art. 49] that it may be divided into three sections, taking the records given by the ordinary seismographs: when seismograms taken with Omori seismographs are examined carefully, the existence of two stages of preliminary tremors may often be distinguished, but it is generally difficult to recognize different phases of the main part as in distant earthquakes; it is even possible, that the corresponding vibrations are included under different divisions.

Illustrative diagrams obtained with Omori seismographs are given in figs. 31, 32, and 37.

72. As in the case of near earthquakes, *the duration of the preliminary tremors* is found to depend entirely on the distance of the origin from the observing station: thus let x denote the arcual distance or the distance along the great circle between the epicentre and the observing station, and y the duration of the preliminary tremors, then from the observation of earthquakes whose x varied between 2000 and 14,000 km., the following equation between x and y has been deduced by Prof. Omori.[1] [See fig. 33.]

$$x^{km} = 6{\cdot}54\, y^{sec} + 720^{km}$$

This equation is practically identical, for large values of x and y with the equation [of Art. 54] deduced from the earthquakes whose x is less than 1000 km. We have, then, the remarkable fact, that the duration of the preliminary tremors is proportional to the arcual distance of the origin. The time taken by each of the subsequent sections of the earthquake motion seems also to be proportional to the arcual distance.[2] [See fig. 34.]

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[1] F. Omori: Horizontal Pendulum Observation of Earthquakes at Hitotsubashi (Tōkyō), 1900; E. I. C. Publ., No. 13, p. 87.

[2] A. Imamura: On the Milne Horizontal Pendulnm Diagrams obtained in Tōkyō; E. I. C. Publ., No. 16.

73. *Periods of vibrations.* The predominating periods in the different sections of the distant earthquake motion observed at Hitotsubashi (Tōkyō) were as follows; those very frequently occurring being given in black letters.

	sec.	sec.	sec.	
1st preliminary tremors	1·04	**4·6**	**8·7**	
2nd ,, ,,	**8·5**	14·8		
3rd section	22·9	27·6		
4th ,,	13·6	17·8	22·3	25·9
5th ,,	**9·3**	13·6		
Tail	**9·6**	16·0		

It will be observed that the two periods of about $4\frac{1}{2}$ and $8\frac{1}{2}$ sec. occur most frequently in the preliminary tremors; this being also the case with the observations made at Hongō.

The different periods of vibrations in the 1st and the 2nd preliminary tremors do not depend on their duration, that is to say, on the distance of the earthquake origin from the observing station. A similar conclusion probably holds good also for the periods in other stages of the earthquake motion.

74. Thus there are, in the 1st and 2nd preliminary tremors, two predominating periods, which may be denoted by P_1 and P_2, and whose mean values are

$$P_1 = 4{\cdot}6 \text{ sec.}, \quad P_2 = 8{\cdot}3 \text{ sec.};$$

now these are practically identical respectively with the two periods, $Q_1 = 4{\cdot}4$ sec. and $Q_2 = 8{\cdot}0$ sec., found for the pulsatory oscillations in Tōkyō [Art. 68.] Moreover the periods P_1 and P_2 do not depend on the distance of an epicentre from the observing station, or on the nature of the disturbance at the seismic origin, but are characteristic of the region about Tōkyō.

We may hence probably explain the existence of the preliminary tremors somewhat as follows:—the waves of the preliminary tremors are transmitted along a deep layer of the earth's crust with a velocity of some 14 km. of which I shall speak presently, and communicate a sort of stress to the superincumbent surface layer of the earth's crust in the region about the observing station: the latter being, in consequence, thrown into its own proper vibrations. In fact, the preliminary tremors seem to be nothing else than the pulsatory oscillations, caused by the waves transmitted along a deep layer of the earth's crust from the origin of earthquakes.[1]

75. Taking the observations of 11 great distant earthquakes,[2] the predominating periods in the different sections of the motion are as follows:—

	sec.	sec.	sec.
1st preliminary tremors	4·1	7·8	13·9
2nd ,, ,,	4·8	8·2	15·0
3rd section	36·1		
4th ,,	27·5	33·7	
5th ,,	20·4	24·0	
6th ,,	11·7	14·9	
7th ,,	14·3		
8th ,,	14·5		
Tail	9·9	14·3	19·8

The durations of the different sections of the earthquake motion are roughly equal to one another; the 3rd and the 4th sections being taken together.

The amplitude of motion is smallest in the 1st preliminary tremors, and greatest in the 4th and 5th sections.

The mean maximum (EW) amplitudes in the successive

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[1] F. Ōmori: Horizontal Pendulum Observations of Earthquakes at Hitotsubashi (Tōkyō), 1900; E. I. C. Publ., No. 13, p p. 84—86.

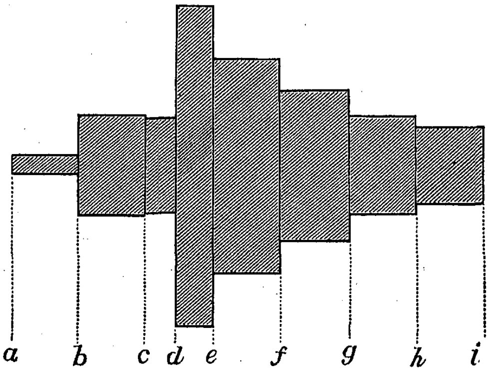
[2] Loc. cit. p. 115.

sections of the earthquake motion, deduced from the observations of nine large disturbances, are as given in the following table, where 2a denotes the actual value, and 2a′ the relative value, the amplitude of motion in the 1st preliminary tremors being taken as 100.

Sections of earthquake motion.	2a mm.	2a′
1st preliminary tremors	0·24	100
2nd ,, ,, ...	1·35	560
3rd section	1·32	550
4th ,, ...	4·36	1820
5th ,, ...	2·93	1220
6th ,, ...	2·02	840
7th ,, ...	1·35	560
8th ,, ...	1·03	430

Fig. 35 illustrates diagramatically the character of motion in the first eight sections of great distant earthquakes, with regard to the duration and amplitude.

Fig. 35.



ab ....1st prel. tremors.
bc ....2nd ,, ,,
cd ....3rd section.
de ....4th ,,
ef ....5th ,,
fg ....6th ,,
gh ....7th ,,
hi ....8th ,,

The Velocities of Propagation of the Vibrations.

76. In calculating the velocities of propagation of distant earthquake waves, it makes a great difference according as we suppose the waves to be propagated along the chord joining the origin to the observing station, or parallel to the surface. Recent investigations would seem to point to the latter as more probable. Calculated on this supposition, the velocities of the different corresponding waves of the earthquake motion come out practically the same, whatever the (arcual) distances; whereas on the chord supposition, the velocities of the corresponding waves come out quite different, according to the distances.[1]

If we denote by v_1, v_2, v_3, and v_5 the velocities of propagation (supposed parallel to the surface) of the waves at the commencement of the 1st, 2nd, 3rd and 5th sections of the earthquake motion, which are usually well marked, their values deduced from the observations in Europe of the recent great Japan earthquakes are as follows:[2]

$$v_1=14{\cdot}1\ ^{\text{km.}}/_{\text{sec.}}\quad v_2=7{\cdot}5\ ^{\text{km.}}/_{\text{sec.}}\quad v_3=4{\cdot}7\ ^{\text{km.}}/_{\text{sec.}}\quad v_5=3{\cdot}3\ ^{\text{km.}}/_{\text{sec.}}$$

The observation of the Caracas Earthquake of Oct. 29th, 1900, at Tōkyō and several European stations gave approximately the same results, viz. $v_1=13{\cdot}6$, $v_2=7{\cdot}2$, $v_5=3{\cdot}4$ km. per second.[3]

The values deduced by Dr. Imamura from a careful examination of the Milne Horizontal Pendulum Seismograms obtained at various stations all over the world are also similar to the above

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1) Ōmori: Horizontal Pendulum Observ. of Earthquakes; E. I. C. Publ., No. 13.

2) Ōmori, loc. cit., p. 137.

3) Ōmori, loc. cit., p. 138.

values: viz. $v_1=13{\cdot}2$, $v_2=6{\cdot}8$, $v_3=4{\cdot}5$, $v_5=3{\cdot}3$, $v_6=2{\cdot}8$, $v_7=2{\cdot}4$, $v_8=2{\cdot}1$ km. per second.[1]

77. The velocity of propagation of the vibrations at the commencement of the main part of a near earthquake was, as I have already stated [Art. 64], found by the method of Seismic Triangulation to be 3·3 km. per second, which is the same as v_5 above. The velocity corresponding to the initial wave of the preliminary tremors of a near earthquake seems to differ very much according to the distance of the origin, but from the equation of duration of the initial vibrations and the distance of the origin [Art. 54], it must be tolerably great; two Formosan earthquakes and two Manila earthquakes gave a mean value of about 11 km. per sec. for this velocity. Quite recently, Dr. Imamura has found that even for earthquakes whose origin is distant less than 1000 km., by taking difference of times of arrival at two stations, which were some 300 km. distant, this velocity comes out to be about 13 km., which is approximately the same as v_1.[2] This, if true, is a further confirmation of the supposition of arcual propagation. An accurate determination of this velocity will, it is hoped, be undertaken in a near future.

78. Prof. Nagaoka's recent investigations[3] of the elastic constants of rocks, of which I shall speak presently, show that the approximate velocities of propagation of longitudinal elastic waves (calculated from the elastic constants of the specimens) varied from little over 1 km. to 7 km. per sec., by far the largest number having a velocity of about 3 km. This seems to show that the waves

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[1] Imamura: On Milne Horizontal Pendulum Seismograms obtained at Hongō, Tōkyō; E. I. C. Publ., No. 16, p. 115.

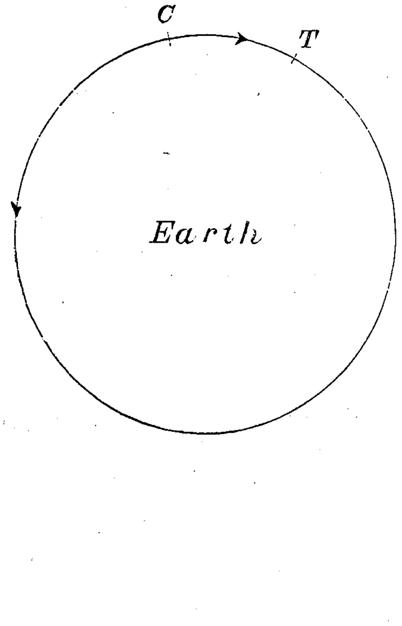
[2] Imamura: Note on the Transit Velocity of the Earthquake motion originating at a near distance; Su. Butsu. K. G., Vol. II, No. 13.

[3] Nagaoka: Elastic Constants of Rocks and the Velocity of Seismic Waves; E. I. C. Publ., No. 4, or Phil. Mag., May, 1900.

in the 5th section in distant earthquake motion and the principal waves in the near earthquake disturbance, both having a velocity of about 3·3 km. per sec. are propagated along the surface of the earth's crust. According to Prof. Nagaoka, older rocks have greater velocity than the new, and we shall have greater velocities as we go deeper down, until we come probably to a stratum of maximum velocity. It is probable, that the waves having velocity v_2=say 7 km., and v_3=say 4·5 km. are transmitted along a layer at some small depth within the earth's crust. For no rock tried, was there such high velocity as 13 or 14 km., but probably such velocity is attained by some tolerably deep stratum,—Prof. Nagaoka's "stratum of maximum velocity."

The above supposition gives a very easy explanation of the fact that the duration of the preliminary tremors is proportional to the arcual distance of the epicentre and the observting station, for this duration is the time between the arrivals of the initial waves of the preliminary tremors and of the main part, and therefore ought to be equal to the distance divided by the difference of velocities, v_1—v_3, which is on our supposition found to be constant.

Fig. 36.



79. *Propagation of seismic waves completely round the earth.* Let T be the observing station (Tōkyō), and C the earthquake origin [fig. 36]. Then there are three sets of motion, which can be distinguished and which we shall denote respectively W_1, W_2 and W_3

waves[1]:—*firstly*, the W_1 waves are those propagated from C to T along the shortest path, parallel to the surface; *secondly*, the W_2 waves are those propagated from C in the opposite direction and arriving at T after passing through the antipode of C; and *thirdly*, the W_3 waves are the W_1 waves, which are propagated beyond T in the same direction, and again arrive at T after making one complete circuit of the earth. Fig. 37 which is the NS component diagram of the Turkestan earthquake of Aug. 22, 1902, recorded at Hongō, Tōkyō, indicates the W_2 and W_3 waves distinctly.

The identification of the W_3 waves is possible only in a very few number of cases; that of the W_2 waves is, however, more definite, being usually characterized by the fact that their period is much slower than those of the preceding vibrations, which form the tail of the W_1 waves.

The average period of the W_2 waves is with a few exceptions very uniform and gives a mean value of 20·4 sec., which is identical with the predominating period in the 5th section; the period of the W_3 waves is also probably nearly the same as that of the W_2 waves. These facts seem to indicate that the W_2 and W_3 waves are the same waves as those which constitute the 5th section of the earthquake proper. That this is probably the case may easily be understood, as the vibrations in the 5th section have large amplitude, while their period is tolerably slow, but not so very long as that of the waves in the 3rd and the 4th sections.

The time interval between the arrival of the W_1 and that of the W_3 waves is $3^h\ 20^m\ 46^s$; this agrees with the time that would be taken by the vibrations in the 5th section in making one complete circuit round the earth, with the velocity of 3·3 km. per sec.

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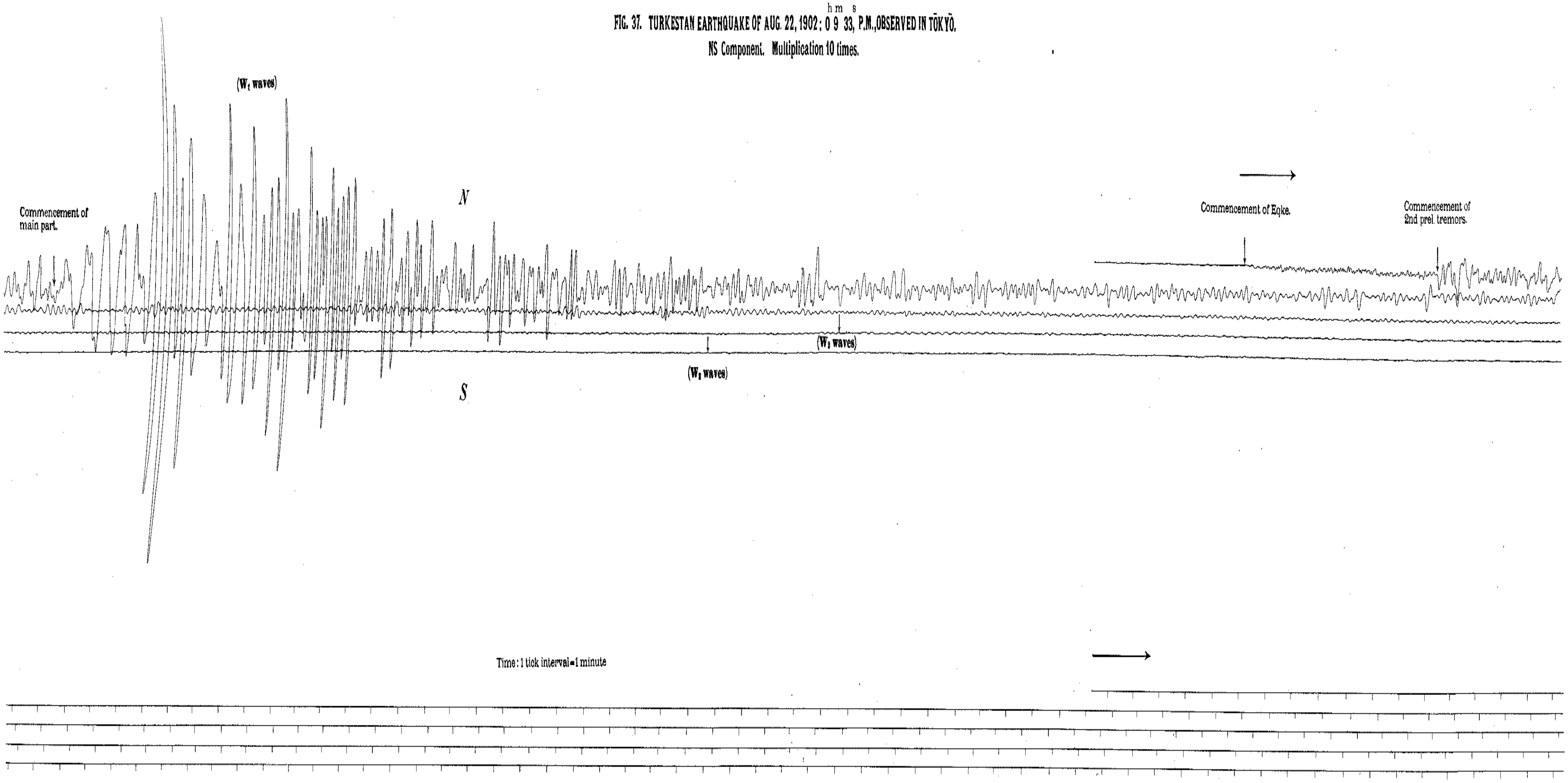
[1] F. Omori: Horizontal Pendulum Observation of Earthquakes at Hitotsubashi (Tōkyō), 1900; E. I. C. Publ., No. 13, p. 119.

FIG. 37. TURKESTAN EARTHQUAKE OF AUG. 22, 1902: $0^{h}\,9^{m}\,33^{s}$, P.M., OBSERVED IN TŌKYŌ.

NS Component. Multiplication 10 times.



The amplitude of the W_2 waves is generally very much smaller than that of the W_1 waves; the motion of the W_3 waves being again much smaller than that of the W_2 waves. This ought of course to be the case, as the intensity of the seismic waves rapidly decreases with an increase of the distance from the centre of disturbance.

In a number of Milne horizontal pendulum photograms, Dr. Imamura has ascertained the repetition, in the W_2 waves, of the 3rd and 6th sections as well as the 5th section.[1]

80. *Longitudinal and Transverse Vibrations.* In the meizoseismal area of great destructive earthquakes, the directions of the maximum motion at different places generally converge to, or are symmetrical about, the epifocal region. Again, it is well known that the macro-seismic motion at great distance from the origin consists mainly of horizontal vibrations. These facts seem to show that the most active part of the earthquake motion consists of longitudinal waves; and we may suppose, therefore, that the velocity of propagation of the most active part in the macro-seismic disturbances, and also of the 5th section in distant earthquakes, characterizes the longitudinal component of the seismic motion. We have, however, no reason to suppose that the transverse component is entirely wanting in the seismic disturbances. Only its amplitude would in most cases be smaller and its velocity of propagation less than in the longitudinal component. Now, according to the results obtained by Prof. Nagaoka,[2] the ratio of the longitudinal to the transverse velocity would be about 1·6: 1 for granite, and 1·5: 1 for andesite. One of the three velocities, v_6, v_7, and v_8, possibly v_8, may be that of the transverse waves; the ratio v_5/v_8 being 1·8: 1.[3]

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[1] E. I. C. Publ., No. 16.

[2] Nagaoka: Elastic Constants of Rocks and the Velocity of Seismic Waves; E. I. C. Publ., No. 4.

[3] Omori: Horizontal Pendulum Observations of Earthquakes at Hitotsubashi (Tōkyō), 1900; E. I. C. Publ., p. 124.

From an examination of Milne Horizontal Pendulum photograms, Dr. Imamura says: "It (6th phase of the principal portion or 8th section) develops itself sometimes quite distinctly and is easily distinguished from the preceding stages.........The velocity comes out to be 2·1 km. per sec., so that the ratio $v_5:v_8$ is 1·5,........."[1]

(D) Nature of Earthquake Motion.

81. The earthquake motion may be linear or tilting or both combined. The important question is: which is it? All the results of the earthquake measurements which I have given are based on the assumption that the earthquake motion or the motion recorded by the seismographs is linear and not tilting. I shall now state some of the principal grounds for this assumption.

82. *First, for the macro-seismic motion.* The length (λ), the period (T) and the propagation velocity (V) of a wave are connected with each other by the well known relation $\lambda = T \times V$, in which V is, say, equal to 3·3 km. per sec. To take an example, let us suppose that in an earthquake the vertical motion amounts to 100 mm.; the period T may be taken at $1\frac{1}{2}$ sec. the period of the principal vibrations in a strong earthquake being seldom less than 1 sec. The wave-length λ then comes out to be about 5 km., that is to say, there is a vertical displacement of 100 mm. in the horizontal distance of $2\frac{1}{2}$ km., the maximum angle of inclination of the ground surface being about 13″. Such a small angle of inclination can not be felt by the ordinary macroseismic instruments, neither can it be directly observed with our eyes. The vertical motion of 100 mm. here supposed can occur only in an extremely destructive

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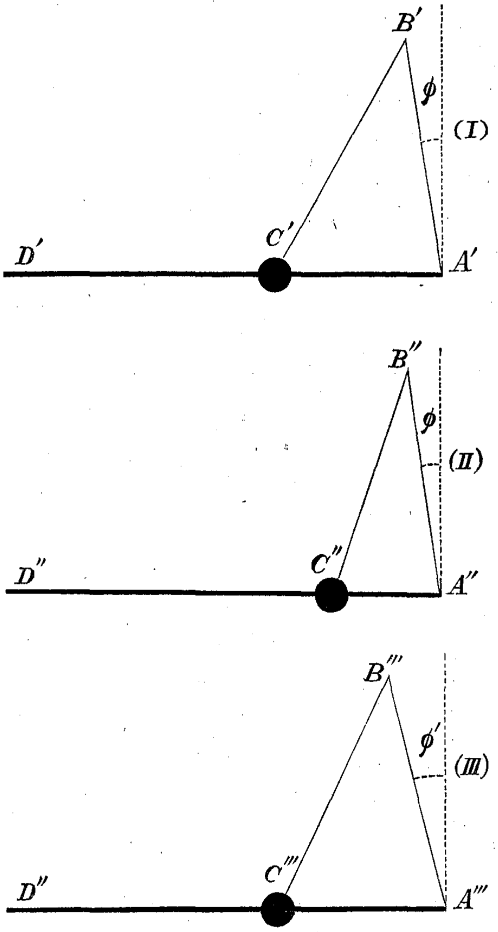
[1] Imamura: On Milne Horizontal Pendulum Seismograms obtained at Hongō, Tōkyō; E. I. C. Publ., No. 16.

earthquake; thus in the severe Tōkyō earthquake of June 20th, 1894, the vertical motion was only 11 mm. With small earthquake vibrations, whose period is short, the wave-length will be shorter than the value above estimated; but at the same time, the vertical motion is infinitesimally small and consequently the angle of inclination of the ground surface will be perfectly negligible.

Thus the earthquake waves, which constitute the macro-seismic motion and have a transit velocity of 3·3 km. per second, can, *in general*, have no sensible tilting motion. They are the vibrations of the material forming the earth's crust, which for small earthquake movements, may well be supposed to lie within the elastic limit of the latter.

Fig. 38.



83. The following is the principle of the experiments made to test the existence or non-existence of tilting in the macro-seismic motion, carried on since 1897 at the Seismological Institute.1) Let there be three horizontal pendulums, I, II, and III [fig. 38], in which C′, C″, C‴ are the heavy bobs; B′C′, B″C″, B‴C‴ the ties; A′C′, A″C″, A‴C‴ the struts; and C′D′, C″D″, C‴D‴ the writing pointers; the lengths

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1) Omori: On the Nature of Earthquake Motion; E. I. C. Hō., No. 32.

A'D', A''D'' and A'''D''' being equal to one another (=L). Further, let the two pendulums, I and II, have a common angle $(=\varphi)$ of inclination of the pendulum axis to the vertical, the ratios of multiplication $\frac{A'C'}{C'D'}$ and $\frac{A''C''}{C''D''}$ being unequal; while the two pendulums, I and III, have equal ratios of multiplication, $\frac{A'C'}{C'D'}$ and $\frac{A'''C'''}{C'''D'''}$, but unequal angles of inclination of the pendulum axes, φ and φ'. The three pendulums are placed with their planes parallel to one another. Thus the first two pendulums would have an equal sensibility for a tilting motion, but different magnifications for a horizontal motion; while the first and third pendulums have an equal magnification for a horizontal motion, but different sensibilities for a tilting motion.

The observtions made with these contrivances of a number of small and also of moderately strong earthquakes show that the tilting motion is absent, or, if present, not large enough to be sensible to the ordinary seismographs.

84. *Next, for Micro-seismic motion.*[1] The observational ground for the assumed linearity of the long-period vibrations due to distant earthquakes is similar to that for the case of the macro-seismic motion, namely, the dependence of the recorded amplitude of motion on the multiplication ratio of the writing pointer, and not on the sensibility of the horizontal pendulum to tilting, in so far as the diagram is not confused by the proper oscillations of the heavy steady mass itself.

Another point, which bears on the question of the nature of the slow earthquake undulations, is the amount of the vertical acceleration which would exist according to the assumption that

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[1] F. Omori: Horizontal Pendulums for registering mechanically Earthquakes and other Movements; Jour. Sc. Coll., Vol. XI. Also: Results of the Horizontal Pendulum Observations of Earthquakes, July, 1898 to Dec., 1899, Tōkyō. E. I. C. Publ., No. 5.

these slow movements are due to the tilting of the ground. As illustrative examples we may take the Ceram earthquake of Sept. 30th, 1899, and the Alaska earthquake of Sept. 4th, 1899; the principal movements in these earthquakes observed in Tōkyō being respectively as follows:—recorded motion=54 mm., period=38 sec.; recorded motion=48 mm, period=16·2 sec. These vibrations, if due to the tilting of the ground, would correspond respectively to the following maximum vertical displacements and accelerations:—

Ceram earthquake:—maximum vertical displacement=1610 mm;
maximum vertical acceleration$=22\,\text{mm.}/\text{sec.}^2$
Alaska earthquake:—maximum vertical displacement=416 mm;
maximum vertical acceleration$=31\,\text{mm.}/\text{sec.}^2$

Again, in the Indian earthquake of June 12th, 1897, the period of large vibrations and the maximum inclination in Europe were, according to Dr. Agamennone, respectively 20 sec. and 12″. These quantities would correspond to a vertical displacement of 1220 mm. and the maximum vertical acceleration of 60 mm. per sec. per sec. Thus, under the supposition of tilting, the vertical displacement must reach often a considerable amount, the maximum acceleration varying, in the examples given above, between 22 and 60 mm. per sec. per sec. Movements like these would be sufficiently intense to be felt by us, and indeed a motion with an acceleration of 50 to 60 mm. per sec. per sec. may be classed as a *strong* earthquake shock. On the other hand, the maximum acceleration of the slow earthquake vibrations, calculated under the supposition of the horizontal motion, is found to be very small, being a mere fraction of one mm. per sec. per sec., an amount much too small to be sensible, or even to be registered by ordinary seismographs. Thus the conclusion is that the slow earthquake vibrations can not, at least generally, be regarded as tilting motion.

85. *Pulsatory Oscillations.* The pulsatory oscillations seem also to be linear, the recorded amplitude depending simply on the multiplication ratios of the writing pointers of the seismographs.1)

86. What has been said relates to ordinary and insensible earthquake vibrations and pulsatory oscillations. In very violent earthquakes, however, waves of short length, which are accompanied by a considerable amount of tilting, may be produced in soft grounds [as stated above in Art. 61]. Again, the ground seems to be subject to diurnal and other periodic changes of level from meteorological and other causes. These changes, the observation of which has not yet been carried on very satisfactorily, form an important subject of investigation in connection with the rigidity of the earth's crust.

87. I have briefly sketched the more important conclusions deduced from the observations, made mostly with Ewing-Gray-Milne and Omori seismographs; the latter is set up at present only in the Seism. Institute (both at Hongō and Hitotsubashi), the Central Meteorological Observatory, Kyōto Imp. Univ., International Latitude Observatory at Mizusawa, and quite recently at a few local meteorol. stations, such as Osaka, Kōbe, Tadotsu, Miyako, Ishinomaki, and several in Formosa and Pescadores; it is hoped to increase the number of such stations. With regard to the results stated both in this chapter and in the preceding one, future observations may cause some of them to be modified, indeed there are several points, on which a revision of the results obtained with the Ewing-Gray-Milne seismographs seem desirable, as I have

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1) Omori: Horizontal Pendulum for registering mechanically Earthquakes, etc.; Jour. Sc. Coll, Vol. XI.

pointed out. Again I think it quite likely for instance, that the amplitude of slow vibrations recorded by any of the present instruments may be smaller than it really is, owing to the friction between the parts of the instrument. Other results will probably have details filled in.

In fact, the results obtained so far are mostly to be regarded rather as first approximations, and we are now entering upon the era of second approximations.

CHAPTER IV. GEOLOGICAL INVESTIGATIONS.

88. *The seismological character of a country* manifestly depends upon *its geological structure;* hence a thorough knowledge of the latter is essential to the proper understanding of the cause of earthquakes, of their distribution in time and space, of their frequency, and of many other things connected with earthquakes proper and other motions of the earth. Fortunately, the Imperial Geological Survey of Japan was organized in 1879, at the suggestion of Prof. E. Naumann of Tōkyō Univ. The excellent work, that the Survey has been and is doing, may by seen from the little pamphlet published by it for this Exposition with a catalogue of its exhibits; from this it will be seen that the reconnaissance survey of the country has been completed, except in the extreme south, and maps, both topographical and geological, published. The Survey publishes, besides maps, Explanatory Texts, Bulletins and Reports, mostly in Japanese.

89. *The Vulcanological Survey of Japan.* The E. I. C. began a detailed study of the new and old volcanoes of Japan as regards their internal structures, their rocks, their foundations and their modes of distribution, at the suggestion and under the direction of Prof. B. Kotô, who says: "In doing so, I can possibly get an insight into the structure of the land; and finally, I may be able to construct the geotectonic map, by means of which we could possibly know the condition underground, and the causes of the regional shaking and local points of earthquakes." *This*

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1) Kotô: The Scope of the Vulcanological Suurvey of Japan; E. I. C. Publ., No. 3.

systematic vulcanological survey is, I believe, the only thing of this nature at present. The volcanoes already surveyed are the Myōkō, the Yoneyama, the Kenashi, the Ōshima (in Izu), the Haruna and Tsunootoshi, the Hakone and Atami, the Volcanoes of Izu Peninsula, the Akagi, the Arafune, the Yatsugadake, the Fuji and Aitaka, the Nikkō group, the Takahara, the Aso, the Nasu, the Niijima (in Izu), and the Iwate; the reports of these surveys, published with maps, in the Hōkoku of the E. I. C. have been already found of use in many ways. In this connection, I should mention Prof. Milne's account of the Volcanoes of Japan, in Vol. IX of the Trans. Seism. Soc.

90. Geologists from Tōkyō Univ., the Geol. Survey and the E. I. C. have not failed to visit scenes of severe earthquakes, volcanic eruptions, tsunamis, subterranean sounds, &c., to inspect the geological side of the phenomena, and their reports in various publications form valuable materials for the further study of the subject. I ought to mention specially Prof. Kotô's epoch-making account of the "Great Fault of Neo" in Central Japan.1) His account of the Shōnai earthquake of 1894 describing the geology of the district shaken and the fault to which he attributes that earthquake2); and that by Dr. N. Yamazaki of the Riku-U earthquake of 18963) are also noteworthy as throwing light upon the discussion about the cause of earthquakes. The account of the Eruption of Bandaisan, June, 1888, by Prof. Sekiya and Assistant Prof. Kikuchi deserves also to be mentioned.4) [For others see the contents of the reports of the E. I. C., in the Appendix.]

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1) Kotô: On the Cause of the Great Earthquake in Central Japan, 1891. Journ. Sc. Coll., Vol. V.

2) E. I. C. Hō, No. 8.

3) E. I. C. Hō, No. 11, or Petermanns geogr. Mitt, 1900; Heft XI.

4) Sekiya and Kikuchi: On the Eruption of Bandaisan. Jour. Sc. Coll, Vol. III.

91. As to the causes of earthquakes in general, many theories have been put forward, which it would be out of the scope of the present address to discuss, even if I were competent to do so. It may however be remarked that almost all recent earthquakes in Japan, extending over a large area seem to be "tectonic", i. e., due to mountain-forming agencies, while in earthquakes accompanying volcanic eruptions, the shaking is confined to a comparatively small area.

CHAPTER V. PHYSICAL INVESTIGATIONS.

92. Earthquakes being due to the strain in the earth's crust, being in fact a violent relief of the stresses causing this strain, which has passed a certain limit, it is reasonable to assume that there would be some relation between earthquakes and physical phenomena which affect or are affected by the strain in the earth's crust. Hence the prime importance of examining the geological structure of the land; hence the reason to believe that the periodicity relations I have mentioned [Chapter II] are not accidental, but are based upon some causal relations; hence the significance of the observation of pulsatory oscillations, as probably indicating changes in the stresses; hence also the presumption in favor of making careful observations of such phenomena, as the Earth Magnetism, Variation of Latitude, Gravity, Changes in underground Temperature, &c., extended, if necessary, over large area and long period. By such observations, taken singly or conjointly, we may at last be enabled to find out some means of predicting the occurrence of an earthquake: we would at least leave nothing untried, as far as our means will allow, that was at all likely to help us in this ultimate object of the Committee. Of the scientific value of such investigations apart from seismological considerations, it is not necessary for me to speak here. Although we have not as yet succeeded in establishing such definite relations as to enable us to make a distinct prediction of an earthquake, (nor was it to be expected that we should arrive at such great result in so short a time with so limited means,) yet the results in some of them at least are such as to encourage us to be patient and continue our investigations. I proceed to give a brief account of some of the work done in this line.

Earth Magnetism.

93. With regard to the Earth magnetism, disturbances have been observed in magnetometers at the time of earthquakes, but no systematic observations have been made with the object of ascertaining if there was any real relation between the two. The E. I. C. therefore decided to undertake this investigation: previously to this, observations had been made at the Central Meteorological Observatory in Tōkyō, since February, 1888, with Mascart's Magnetograph; the E. I. C. then initiated observations with similar instruments in Nagoya and Sendai in Sept., 1893; in Nemuro in Oct., 1896; and in Kumamoto, in Sept., 1898. In 1901, the Nagoya set was removed to Kyōto, chiefly in consequence of an electric railway passing too near the station. We thus have now *continuous magnetic observations at five places* distributed over Japan as evenly as circumstances allow. The photographic records are examined, and the results published periodically by the Central Meteorological Observ.

Systematic comparison with earthquake observations is being carried on, although, I am sorry to say, nothing has been published since 1897.

94. On several occasions, magnetic disturbances seem to have preceded or accompanied earthquakes:

Towards the end of 1893, on several occasions, the horizontal components at Nagoya station was disturbed for several days continuously, being followed after an interval of quiet of a day or two, by an earthquake; notably there was a disturbance lasting from Dec. 14 to Jan. 3, 1894, followed by a disturbance in declination and intensity (which was also observed at Tōkyō and Sendai) continuing up to 7th; three days afterwards there was a severe earthquake.[1]

For about a week before the severe earthquake in Shōnai district of Oct. 22, 1894, there was a magnetic disturbance recorded at Sendai; also to a smaller degree in Tōkyō, and in a still smaller degree in Nagoya.[2]

For about four days before the great seismic "tsunami" along the north-eastern coast of June. 15, 1896, a disturbance in the horizontal component and declination was recorded at Sendai, and in a smaller degree at Tōkyō, but not at all at Nagoya.[3]

Preceding the severe earthquake in Ugo and Rikuchū of 1896, magnetic disturbances were recorded in Sendai, Tōkyō and Nagoya, from midnight of the 29th to about 10 p. m. of 30th, the earthquake taking place about 1. 30 a. m. of 31st.[4]

From 5th to 6th of May, 1900, disturbances were observed in all the five stations, and on 12th, at 2. 20 a. m., a tolerably severe earthquake shook the Rikuzen district.[5]

These records will require careful examination and extensive comparison with magnetic observations abroad, as well as records of earthquakes and pulsatory oscillations, before we can consider any relation established between these phenomena.[6] In some few

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[1] E. I. C. Hō., No. 2, pp. 141-144.

[2] E. I. C. Hō., No. 11, p. 35.

[3] E. I. C. Hō., No. 11, p. 35.

[4] E. I. C. Hō., No. 11, p. 106.

[5] E. I. C. Hō., No. 32, p. 127.

[6] See also Dr. Honma's discussion of the Records from Jan. 1896 to Aug., 1896., in E. I. C. Hō., No. 32, pp. 131-144.

instances where the disturbances seemed to be of limited extent, their vertical variations were calculated by the method given in Jour. Sc. Coll., Vol. XIV, § 12, from the sign of which the question whether the source of disturbance is above or below the earth's surface can be answered; the results are reserved from publication owing to the incompleteness of the magnetograph records. They however show that the depth or height of the source is small compared with the distances between the stations. Either three observatories in close proximity or six over Japan will be suitable for the kind of calculation there dealt with, the former giving immediately the differential coefficients of the disturbing forces with regard to the coordinates, and the latter giving quadratic expressions from which the differential coefficients may be calculated. It is at all events certain, that this investigation is one of the few means at present available for diagnosing the state of underground stress and a promising one, and it is desirable that it should be further developed.

I may mention here that at the request of the German government, the E. I. C. has made magnetic observations during the Antarctic Expedition of the "Gauss," in accordance with the program proposed.

95. Besides these continuous observations, the E. I. C. made *a Magnetic Survey of Japan*, during the years 1893–6, under the direction of Prof. A. Tanakadate. The survey had to be extended over so many years, owing to the fact that Prof. Tanakadate and other members of the survey could only be absent from their other duties during the summer vacations. Previously to this, there had been two surveys; one was made in 1882-3 by Messrs. Sekino and Kōdari, members of the staff of the Imperial Geological Survey, and the result was presented at the International Geological Congress at Berlin in 1885; it is published in a pamphlet by Dr. Naumann, entitled "Die Erscheinungen des Erdmagnetismus in ihrer Abhängigkeit vom Bau der Erdrinde" (Stuttgart, 1887). The other was made in 1887 by two parties respectively under Prof. Knott and Prof. Tanakadate; the result is given in the Jour. Sc. Coll., Vol. II, pp. 163-262. In Dec., 1891—Jan., 1892, a party under Professors Tanakadate and Nagaoka made a magnetic survey of the district about Gifu and Nagoya, to investigate the effect of so great a seismic event as the Mino-Owari earthquake was, on the magnetic elements of the country; an account of this survey is given in the Jour. Sc. Coll., Vol. V, pp. 149-192, showing that there has been a most remarkable change in the Isomagnetics of the district. How much of this was due to the same cause as the earthquake and how much to secular or other changes had to be investigated. This may be said to be one of the reasons, that induced the E. I. C. to undertake a general survey of Japan. The report of the last survey has just been published as Vol. XIV of the Jour. Sc. Coll. In it, Prof. Tanakadate says :

"The object of the survey was to get a closer view of the "distribution of magnetic force in the country than hitherto has "been done. It is hoped that we may obtain in this way some "insight into the tectonic character of the country which might "throw light upon the distribution of earthquake disturbances with "regard to time and space.

"The object was twofold, first to obtain a general or normal, "as it is sometimes called, distribution and second to get the "extent and nature of local disturbances in special districts. With "the first point in view a camparatively large number of stations "were taken in places which were apparently free from distur-

"bances of any great magnitude; and with the second point in "view observations were made in volcanic regions or in places "where violent geological changes are supposed to have taken "place. How near we have come to realize those expectations is "clearly shown in the maps. It will be seen that we have done "something toward the first, but for the second a much more "extended series of observations are needed, although we believe "that some of the prominent points are brought out by the "present survey."

Variation of Latitude.

96. As already stated, it is not unreasonable to suppose that there may be some relation between the seismic phenomena and the variation of latitude. The E. I. C. therefore on its organisation at once resolved to undertake the observations of latitude in Tōkyō: it took however some time before a Wanschaff's Zenith Telescope of 81 mm. aperture was procured, and the observations were only begun in July, 1895 by Dr. H. Kimura, at the Tōkyō Astronomical Obs., the reports of which are given in the E. I. C. Publ., Nos. 1 and 2. Subsequently, this work was transferred to the Geodetic Commission, at the same time that it was decided to establish the Observatory of the International Geodetic Association at Mizusawa.

The result of the examination of the mean monthly values of the latitude of Tōkyō (Astronomical Observatory) for nearly 8½ years between Aug. 1895 and Dec. 1903, with reference to earthquakes in Japan, shows that all the destructive earthquakes occurred exactly or very nearly when the latitude was at a maximum or a minimum. The non-destructive extensive earthquakes also indicate a similar tendency, though in a less marked degree. Small earthquakes seem, however, to have no particular relation to the latitude variation.[1]

With regard to the seismic periodicities, we have seen [Art. 12] that the epochs of the greatest activity of destructive earthquakes in Japan recurred on the average every 13⅓ years, and [Art. 14] that the seismic activity at Kyōto presented a period of about 6½ years. In this connection, it is interesting to note that, according to Dr. H. Kimura, who has studied the latitude variation during the interval between 1890 and 1902, the polar motion has a six years' period, the maximum deviations of the instantaneous pole having occurred in 1891 and 1897.

Gravity.

97. Measurements of gravity have been made in Tōkyō by several observers. Of these, the first was in 1878 by Professors Ayrton and Perry,[2] with a pendulum 9·3 metres long, giving the result $g=979{\cdot}82$ cm./sec.^{2} The next was in 1880 by Prof. T. C. Mendenhall[3] with a Borda's pendulum made by Salleron, giving $g=979{\cdot}84$ cm./sec.^{2} In 1883, Messrs. Smith and Pritchett[4] of the U. S. Coast and Geodetic Survey made observations with four pendulums, their results being $g=979{\cdot}82$ cm./sec.^{2} for pendulums No. 1—No. 3. and 980·0 for No. 4. The measurement made in

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[1] F. Omori: Note on the Relation between Earthquakes and Changes in Latitude; E. I. C. Publ., No. 18. For results in Europe, see Prof. Milne's report on Earthquakes and Changes in Latitude, Brit. Ass. for the Adv. of Sc., Rept. for 1900, p. 107; and Dr. A. Cancani: "Sopra un'ipotetica Relazione fra le Variazioni di latitudine e la frequenza dei terremoti mondiali." Bolletino della Soc. Sismologica Italiana, Vol. VIII. pp. 286–290.

[2] Phil. Mag., April, 1880.

[3] Memoirs of Sc. Dept., Tōkyō Univ., No. 5.

[4] U. S. Coast and Geodetic Survey, Report, 1884.

1884 at Ogasawara-jima (Bonin Island, Latitude 27° 4′ 11″ N) gave the value $g=979{\cdot}47$.

98. The remarkable point to be noticed is that *all these values are greater than is to be expected at the corresponding latitude.* Was this due to some error in the measurements? Or was it real? The value of g is as a rule greater on islands than on the continent: was this the case here? If so, what did it signify? Did it indicate some peculiarity in the internal structure of these islands? As Prof. Nagaoka says: "In Ermangelung einer genauen Messung war es sehr wünschenswert die Beobachtung mit einem anderen feineren Instrumente zu wiederholen und die Frage aufzuklären, ob ein bedeutender Unterschied zwischen dem berechneten und dem beobachteten Wert wirklich bestehe. Nicht nur von der geodätischen und physicalischen Seite schien es höchst interessant für die Erdbebenforschung die Dicke der störenden Schicht auszurechnen, da diese Schicht offenbar mit der Häufigkeit der Erdbeben in unserem Land eng verknüpft sein wird."[1] The E. I. C. therefore decided to make a more accurate determination of the value of g, than had been made hitherto, and the work was placed under the charge of Prof. Nagaoka. The Imperial Geodetic Commission having decided to make gravity determination a part of its work, the work together with the instruments already purchased was handed over to that Commission, Prof. Nagaoka remaining in charge as before. In 1899, absolute measurements were made in Kyōto, Kanazawa, Tōkyō and Mizusawa. The relative measurements connecting Tōkyō with Potsdam, and with other localities in Japan have since been going

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[1] Nagaoka, Shinjō and Ōtani: Absolute Messung der Schwerkraft in Kyōto, Kanazawa, Tōkyō und Mizusawa mit Reversionspendeln ausgeführt, Jour. Sc. Coll., Vol. XVI, Art. 11.

on; and the result has been published in the Comptes Rendus of the 14th meeting of the International Geodetic Association at Copenhagen in 1903. The value of *g* is 979·814 cm./sec.^{2} (that of Potsdam beings 981·290) from which it appears that the difference between the calculated and observed values is within the limit of error of observation and presents no peculiarity. The observations[1] made last year at five stations on the east coast of the Asiatic continent, viz. Singapore, Hongkong, Zikawei, Hankow and Shasi tend to confirm the result that gravity in Japan has a continental rather than insular character. From other observations, made with the same instruments, there are reasons to believe that in mountainous regions the force of gravity presents great anomalies. That these and future determinations of gravity at properly chosen spots will throw much valuable light upon the internal structure of the land, cannot be doubted.

Underground Temperature.

99. It was proposed to bore deep wells in properly chosen spots and to make measurements of temperature at different depths in these wells. We should thus get a knowledge of the distribution of temperature within the earth's crust, and if we can get a sufficient number of wells, of the *underground isothermals*, which will not only throw light upon the tectonic character of the land but also by their changes will indicate internal changes in stress, so that we may thus be able to predict an earthquake. A well was begun in the Tōkyō Univ. ground in Hongō, which reached a little

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[1] Shinjō, Ōtani and Yamakawa: On the Gravity and the Magnetic Survey at five stations in Eastern Asia; Abstract in Su Buts. K. G., Vol II.

over 400 metres in 1898; it was found advisable to stop at this depth, on account of the stratum met with. Reports of the boring operations and of geology of the well will be found in the E. I. C. Hō., Nos. 2 and 20. It has been found unfortunately impossible to continue boring in different localities at present, for want of funds, but the Committee has availed itself of wells which had been bored for other purposes, such as the supply of good water, or experimental boring for minerals. The first report by Prof. Tanakadate is in Hōkoku No. 45, containing measurements made in the Univ. ground well, in Yokohama, and in Fukushima, also measurements in Sasago and Kobotoke railway tunnels, the former of which is the longest in Japan, having a length of about fifteen thousand feet. The following is the result of measurement taken during 35 days, from April 27 to June 2, 1903, in the first mentioned well:

Depth below the top (metres)	Highest temperature during the period of observation.	Increase of temperature per 100 metres.	Depth for an increase of 1° C.
20·2	15°·10 C		m
81·3	16·88	2°·91 C	34·3
176·5	19·28	2·52	39·6
269·0	21·57	2·47	40·5
360·9	23·62	2·23	44·8

Seiches.

100. Under this head, I include not only the measurement of seiches in the ordinary acceptation of the term, viz. the periodic oscillations of the water of lakes, but also investigation into the existence of similar periodic oscillations in such bodies of water as bays, gulfs, straits, &c. I have already noticed

[Art. 30] Prof. Omori's discussion of the causes of "*tsunami*," and the examination of the records of tide-gauges, which seem to point to the existence of such movements. An account[1] of the observations of seiches in Lakes Biwa and Hakone during the summer of 1901 will be found in the Su. Buts. K. G., Vol. I., No. 15. Observations have also been made in Osaka Bay and on the coasts of Tosa, Kii, Shimōsa and Rikuzen, with a *portable mercurial tide-gauge* specially devised by Dr. S. Nakamura,[2] which clearly point to the existence of seiche-like oscillations at these localities.[3] In the same number, is a very interesting article by Prof. Nagaoka on "*tsunami*," in which he extends Green's investigation to waves in a narrow and shallow channel of symmetrical section, and deduces an expression for the elevation of water, which will explain in a general way the nature and origin of "tsunami": he ascribes the frequency of "tsunami" along the eastern or Pacific coast of Japan to the presence of the Kuroshiwo or Japan Current; this current running nearly parallel to the coast he considers as forming an elastic boundary of a narrow band of water enclosed between the coast and itself, in which, as well as in bays and straits, periodic oscillations like the seiches of lakes exist. These being occasionally excited by local variations of atmospheric pressure, earthquakes, &c. give rise to high and destructive waves on account of the contour and shallowness of the shore. Further observations are necessary to the elucidation of this question, which may lead to important results, perhaps even to the prognostication of "tsumami."

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[1] In English. A French translation is given in Archives des Sciences physiques et naturelles, Genève, t. XV, pp 558-566; see also Zeitschrift für Instrumentenkunde, XXIII Jahrgang, Nov. 1903.

[2] For a description of this instrument see Su Buts. K. G. Vol. I, No. 15, and also Zeitschrift für Instrumentenkunde (loc. cit).

[3] The results have not yet been published.

Changes of the Level of Water in Wells.

101. Dr. S. Nakamura had observed periodic variation of the level of water in the well in the Univ. ground ; observations were subsequently made by Dr. K. Honda, with the instrument used in Seiches observations, and it was found that in general, there were two maxima and two minima in every 24 hours, the amplitude varying from 3 cm. to 1 cm. the phases coinciding with those of the tides in Tōkyō Bay; near full and new moons, the succession of the daily max. and min. is very regular, amplitude being decidedly greater than at quadrature; near quadrature, they occur just in the same phase as those of barometric changes; high barometer causes a lowering of the level, and vice versa; the rain does not seem to affect the level.(1) Observations made at other wells have given approximately the same results.(2) These results showing variations in the underground pressure with tides and barometic pressure are specially important when taken in conjunction with the observations of Prof. Omori and Asst. Prof. Imamura as to earthquake frequency [Chapter II]. This investigation is to be regarded as a part of the study of the elastic tides in the earth's crust.

Two weak earthquakes occurred during the above measurements in Tōkyō, and it was found that the level curves were abnormally disturbed by zigzags which extended for 4 or 5 hours both before and after the earthquakes: this will require further investigation.

Determination of the Elastic Constants of Rocks.

102. This work was commenced in 1898 under the direction

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1) Su Buts. K. G., Vol. II, No. 6.

2) Su Buts K. G., Vol. II. No. 9.

of Prof. Nagaoka; I quote the following from his first report:[1)]

"The vibration of the earth's crust has from time to time been a favourite subject of discussion among the elasticians, and the propagation of seismic disturbance is a problem, whose solution has long been hoped for, both from the theoretical and the empirical point of view. With improved instruments, seismologists have recently determined the velocity of propagation with tolerable accuracy, but very little is known of the elastic nature of the medium through which the vibration has travelled. The resources from which physicists and seismologists draw their theoretical inferences are so scanty, that among the numerous rocks which constitute the earth's crust, only a few of the most commonly occurring rocks have had their physical properties investigated. The questions of elasticity, having close bearing with the deformation of the earth's crust, have repeatedly been a subject of research by several distinguished elasticians as Lord Kelvin, Boussinesq, Cerruti, and Chree. But we are baffled in our attempt to apply the result of subtle analysis to the actual problem, from the lack of our experimental knowledge as regards the elastic nature of the diverse rocks, which compose the outer coating of our planet. The present experiments were undertaken with a view to fill these gaps, and to supply on the one hand the wants of physicists, whose aim is to apply dynamics to the study of the geological phenomena, and on the other to meet the needs of seismologists, engaged in solving the problems touching the propagation of seismic waves."

First experiments were made by Prof. Nagaoka to determine Young's modulus and modulus of rigidity of about 100 specimens

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1) Nagaoka: Elastic Constants of Rocks and the Velocity of Seismic Waves: E. I. C. Publ., No. 4. Also, Phil. Mag, 1900.

of ordinary Japanese rocks; it was found that they were not generally isotropic; archaean and palaeozoic rocks could be cut into proper shape for experiment only in a certain direction as they were generally of schistose structure and extremely brittle in the direction perpendicular to it, there being naturally great difference in the elasticity in these directions; eruptive rocks were generally free from such directional behavior, but when subjected to continuous application of stress, the difference could be noticed. But as the directions of the axes of symmetry could not be determined simply, single moduli of elasticity and rigidity were determined for each specimen and the velocities of propagation of longitudinal and transverse elastic waves through it were calculated from these as if it were isotropic. These velocities range, for the longitudinal waves, from 7 km. to little over 1 km. per second, by far the largest number however having a velocity of about 3 km., which agrees very well with the observed velocity (3·3 km. per second) of the principal waves of an earthquake so that this may be taken to be the average velocity of propagation of a surface wave. [See Art. 77]. Such velocity as 14 km., which is that of the preliminary tremors, can be accounted for by supposing that as we go deeper into the earth's crust, the ratio of elastic constants to density increases: indeed the experiments seem to show that the elastic constants and the density increase with the age of the rocks, but the former more than the latter; and it is quite possible that *there may be a stratum of maximum velocity of propagation.* As Prof. Nagaoka points out, this hypothesis would give a very simple explanation of the fact that the duration of the preliminary tremors in the diagram of a distant earthquake is linearly proportional to the distance.

103. It was also found during these experiments that in some rocks Hooke's Law does not hold even for small flexure and torsion, the deviation being more marked in torsion than in flexure, and that there is a remarkable "hysteresis" in the relation of stress to strain. Special experiments were then made by Dr. Kusakabe under Prof. Nagaoka's direction to determine this.

For more than thirty specimens of different kinds of rocks, from archaean to quaternary, elastic constants were experimentally measured under different conditions. In both twisting and bending, couple and force respectively were made to change their values cyclically from positive to negative or *vice versa*, passing through zero continuously.

In almost every rock, not only no definite strain is associated with any given stress, but there is also no definite gradient in passing through a given state. That is to say, in the relation of stress to strain, rocks exhibit a marked hysteresis.

When its complete history is given, however, the amount of strain at any time under a given stress may be expressed by a formula, deduced from an empirical law of yielding, to sufficient approximation. General behavior of rocks may be studied by mere mathematical treatment of the above formula, the Hysteresis function.

As elastic constants, both moduli of rigidity and elasticity, generally increase from cainozoic to archaean rocks with great rapidity, the velocity of the seismic wave would increase with the ages of rocks through which the wave is propagated.

The amount of hysteresis decrease from the new rocks to the old ones. As a wave propagated through a medium of great hysteresis fades more rapidly than that through one of less hysteresis, the seismic wave conductivity of rocks is least for cainozoic rocks and, increasing from mesozoic to palaeozoic rocks, it becomes many times greater for archaean rocks.

Elastic constants seem to be affected by temperature change. In ordinary temperature, elastic constants of sandstone diminish with rise of temperature. Both moduli of rigidity and elasticity are maximum at the temperature of about 9° C.

Discussions as to the relation between amplitude of seismic waves and velocity of propagation, and the relation between the hysteresis and after-shocks based on these experiments are also very interesting. Experiments will be continued with more specimens.[1]

It may be remarked here that experiments to determine heat conductivity of different rocks would likewise lead to important results, and it is hoped to make these experiments.

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[1] E. I. C. Publ., No. 14; Jour. Sc. Coll. Vol. XIX, Art. 6; Su Buts. K. G., Vol. I, No. 14, and Vol. II, No. 11

CHAPTER VI. PRACTICAL.

104. One of the objects of the organization of the E. I. C. is, as already stated, to investigate what can be done to reduce the disastrous effects of earthquake shocks to a minimum by the choice of proper structure, materials, position, &c. For this it is necessary on the one hand to know the nature of the earthquake movements, &c., and therefore most of the investigations mentioned above have an important bearing on this question; on the other hand it is evidently important to know what effects strong earthquake shocks have produced and are likely to produce on existing structures and buildings. With this last end in view, the Committee has collected reports from experts, whenever there has been a destructive earthquake: it has also made many experiments on purpose to find out these effects.

Reports.

105. Among the valuable reports concerning destruction of buildings and engineering structures in the E. I. C. Hōkoku, I may mention the following:

Report on the damage to the Tōkaidō railway caused by the great Mino-Owari earthquake of 1891, and on the work of restoration, by Dr. K. Haraguchi, the chief government railway engineer. With 33 Sheets of maps and drawings. E. I. C. Hō, No. 1.

Reports by Dr. Emori, chief engineer of Aichi Prefecture, and Dr. T. Sayegi, government engineer, on the effects of the same earthquake in the prefectures of Aichi, Gifu and Miye. E. I. C. Hō, Nos. 2 and 3.

Report on the damage to buildings caused by the Hokkaidō earthquake of March 22, 1894, by Dr. K. Ishii, Asst. Prof. of Architecture in the Engineering Coll., Tōkyō Imp. Univ. E. I. C. Hō, No. 3.

Reports on the damage caused by the severe Tōkyō earthquake of June 20, 1894, communicated by Messrs. K. Tatsuno, T. Katayama, T. Sone, and T. Nakamura (E. I. C. Hō, No. 4, with 109 pls.); by Messrs. Tsukamoto, Noguchi and Yamazaki (communicated by Prof. Tatsuno and Prof. Nakamura, E. I. C. Hō, No. 7, with 28 pls.)

Reports on the damage caused by the Shōnai earthquake of 1894, by Prof. Omori (E. I. C. Hō, No. 3, with 23 pls.); by Prof. T. Nakamura, (ditto with sketches); by Dr. T. Sone (ditto with sketches); communicated by Prof. Tatsuno and Prof. Nakamura (E. I. C. Hō, No. 7, with 122 pls.); and by Dr. M. Noguchi (ditto, with 10 pls.).

Reports on damage to buildings caused by the great Riku-U earthquake of 1896, by Prof. Nakamura, and by Dr. Sone (both in E. I. C. Hō, No. 11).

Reports on buildings damaged by the great Indian earthquake of 1897, by Prof. T. Nakamura (E. I. C. Hō, No. 22, with 42 pls.); on the Engineering structures in Assam, damaged by the same earthquake, by Dr. T. Koyama (E. I. C. Hō, No. 25, with 41 pls.).

These reports have been very valuable not only to the Committee but to engineers, architects and builders in general, in showing the mistakes and defects to be avoided, and precautions to be taken against earthquake shocks. [I append here a few plates showing some of the effects of the earthquake shocks.]

Fig. 39. NAGOYA SPINNING MILL.

Showing the effects of the Mino-Owari Earthquake of 1891 on a Brick Building and on a Chimney.

Fig. 40. NAGOYA CASTLE.

Showing the slight effects of the Mino-Owari Earthquake of 1891.

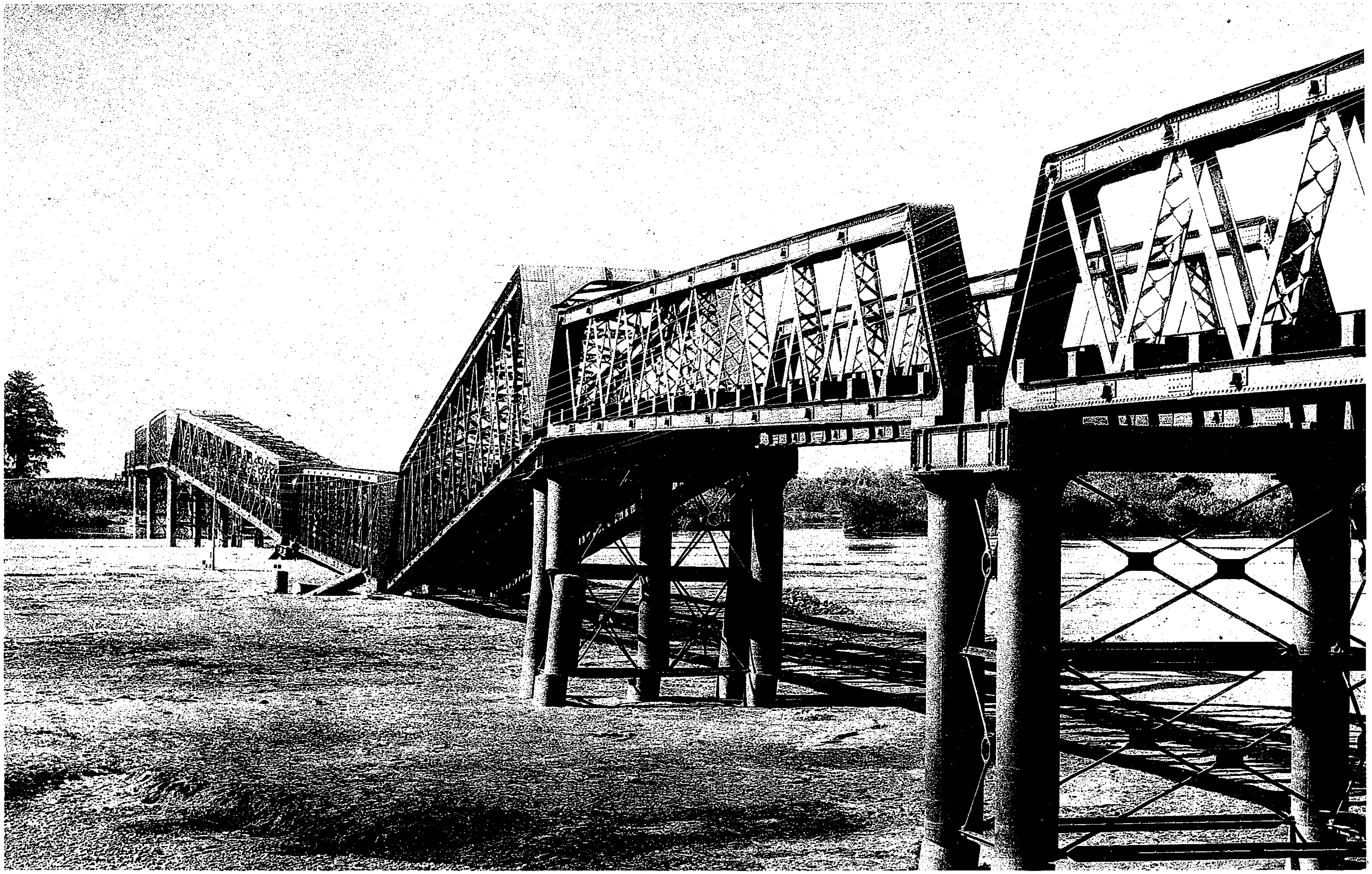

Fig. 41. NAGARAGAWA BRIDGE.

Showing the effects of the Mino-Owari Earthquake of 1891.

Fig. 42. BIWAJIMA.

A Suburb of Nagoya, showing the Destruction of Japanese Houses and a Railway Culvert, in the Mino-Owari Earthquake of 1891.

Fig. 43. Sakata Primary School.

Showing the shearing effect, and the projecting porch thrown down (Shōnai Earthquake of 1894).

Fig. 44. Yamagata Primary School.

Showing a large crack in the ground. the building uninjured (Shōnai Earthquake of 1894).

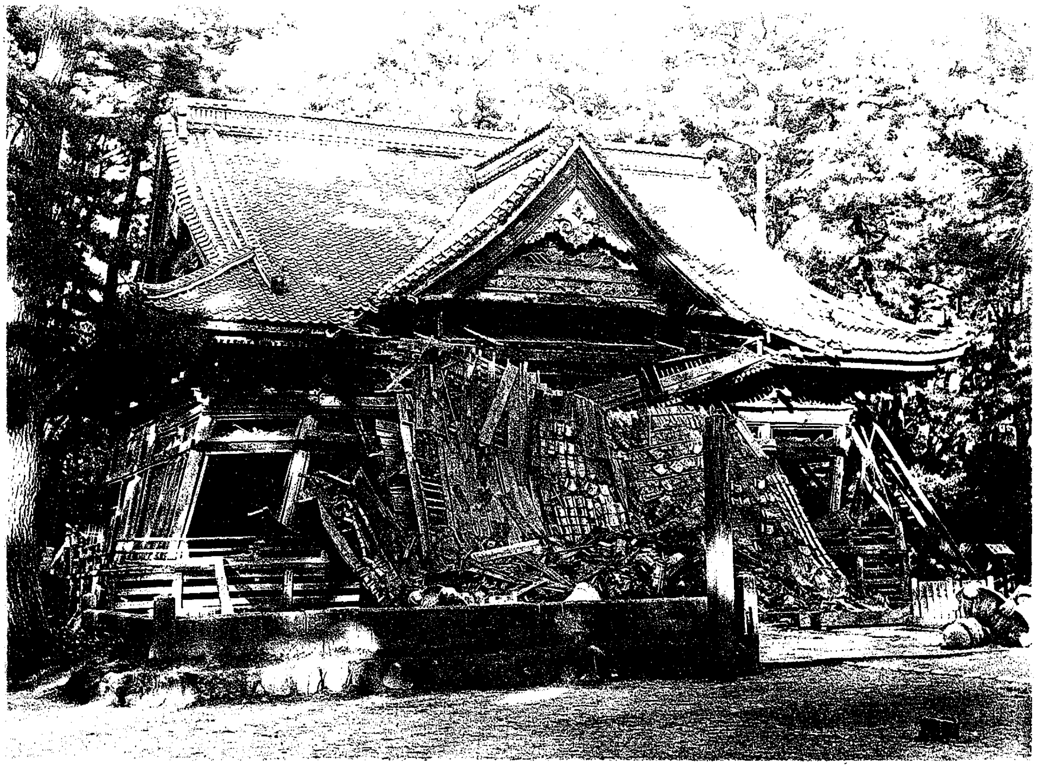

Fig. 45. A Temple in Sakata.

Showing the shearing effect, and the projecting part thrown down (Shōnai Earthquake of 1894).

Fig. 46. A Rustic Bridge.

Damaged by the Shōnai Earthquake of 1894.

Experiments relative to Soil.

106. To this class belong the experiments already described, as to the relation of the soil and shocks [Arts. 59, 60]. Experiments with regard to vibrations in pits and cutting off or intercepting vibrations by means of trenches dug around a building [Art. 62]; marginal vibrations [Art. 63], &c., all have their applications in this connection.

Strength of Materials and Joints.

107. The E. I. C. was obliged to include the determination of the strength of materials, and of joints, among its work, as there has been no systematic work done in this most necessary line. The reports of various tests of timber from different parts of Japan will be found in the E. I. C. Hō, Nos. 2,3 and 35 (by Prof. B. Mano); Nos. 15 and 40 (by Prof. S. Tanabe). Experiments were also made with bricks jointed under different conditions with different mortars, the results of which are reported in the E. I. C. Hō, Nos. 10, 12 and 23 by Prof. S. Tanabe.[1]

The Earthquake-proof Brick Building.

108. This structure is built in the Tōkyō Univ. ground at Hongō, on a solid concrete foundation, and covers a square area of nearly 83 sq. metres. The walls are of parabolic section with vertex downwards [as shown in fig. 47]; 5·5 m. high, 2·4 m. thick at the ground level, 0·7 m. thick at the top. A tiled roof

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[1] Also in E. I. C. Publ., No. 3, pp. 33–83.

with skylights rests loosely on the walls; the entrance about 2·6 × 3·4 m. is the only opening in the walls. The walls were made of parabolic section, that being the section giving uniform strength throughout the height:⁽¹⁾ the cements and mortars were carefully tested before being used; and the details of construction have been reported in the E. I. C. Hō, No. 1, for future reference. The object in building this structure, which was designed by Prof. K. Tatsuno, is to have an earthquake-proof building, that will stand any shock likely to occur in Tōkyō, and will serve as a sort of standard, with which to compare the effects of a shock on ordinary brick buildings: it is also very useful as a solid Seismological Observatory.

Movements during Earthquakes of Walls of Brick Buildings.

109. In 1883-1884, Prof. Milne made a series of highly interesting measurements with duplex pendulum seismographs of the movements produced by earthquakes in certain buildings in Tōkyō. For an account of his experiments, you are referred to Trans. Seis. Soc., Vol. XII.

As damage to brick buildings caused by an earthquake is generally due to the fracturing of their walls in consequence of strong horizontal motion, it is important to make earthquake measurements at different portions of the walls.

Between 1894 and 1898, Prof. Omori made measurements with Ewing's Horizontal Pendulum Seismographs of the earthquake motion of the external wall of the upper west corridor of the Engineering College of Tōkyō University, the instrument being fixed near the top of the wall at the middle of its length.

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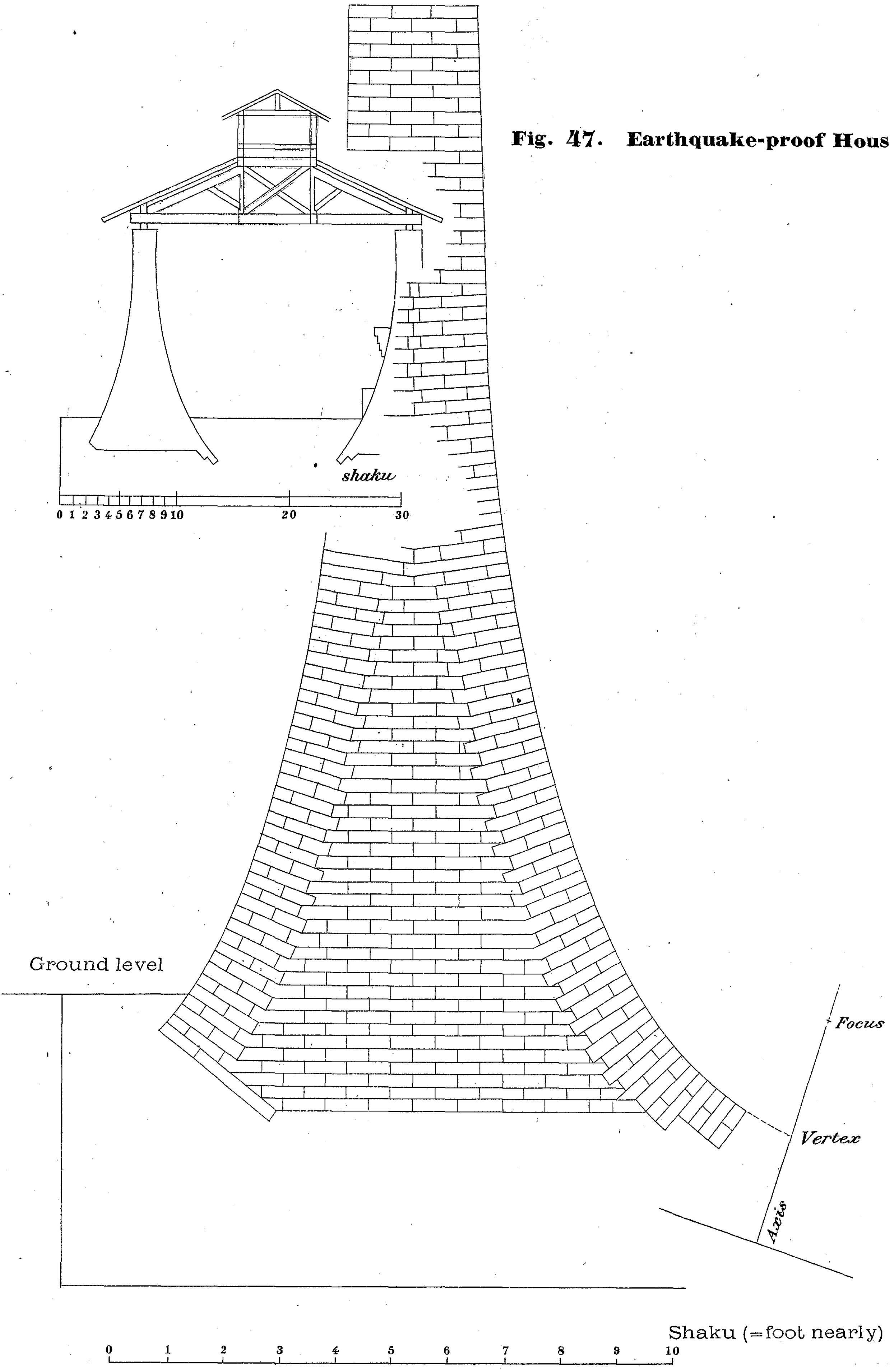
1) Omori: Seismic Experiments on the Fracturing and Overturning of Columns; E. I. C. Publ., No. 4, p. 107, or E. I. C. Hō, No. 28.

Fig. 47. Earthquake-proof House.



Comparing the diagrams so obtained with those obtained on the ground, it was found that, in the case of small earthquakes, which consisted of vibrations of comparatively slow period, that is, above 0·5 sec., the motion was practically equal in the upper story and on the ground surface. On the other hand, in earthquakes which consisted of quick-period vibrations, the motion at the top of the wall was greater than that of the ground surface in the average ratio of 2:1. As the period of vibration was the same for the two places of observation, it seems that in shocks of violent nature the wall, on which the roof rests, behaves like an inverted pendulum, its motion synchronizing with the earthquake motion. Practically, in destructive earthquakes, the damage of two-storied brick buildings is in general limited to the upper story. Thus it is not seldom that the walls of the lower story remain uninjured or only slightly cracked, even when the damage to the upper story is so severe that the walls are knocked down and roof falls in, evidently owing to the magnification of motion in the higher part of the walls.[1] [See fig. 39.]

Another series of measurements related to the eastern end wall of the Natural History Museum, which is a two-storied brick building situated not far from the above. The total height of the wall was 53 feet; the seismograph having been attached to the wall at a height of 31 feet from the ground. The wall, which was evidently a weak one, was shaken considerably by earthquakes; the duration and amplitude of motion being nearly three times those at the ground surface. In this case, the period of vibration of the wall was practically constant, the mean value being 0·33 sec. This shows that the wall behaves in earthquakes like an elastic

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[1] E. I. C. Hō, No. 29, or E. I. C. Publ., No. 4, pp 7–11.

spring and executes vibrations with its own period, whatever the period and amplitude of the ground motion may be. However in cases of very slow vibrations, say of period longer than 2 seconds, the movements are felt equally on the ground and at the top of the wall.1)

Finally, the earthquake motion measured at the 3rd story of the Mitsu-Bishi Bank, a brick building which is situated on the low ground of Tōkyō, did not differ from that at the basement.

The above examples will show that the movements of the walls of brick buildings produced by earthquakes differ very much according to the quality of the structure.

Wooden Houses.

110. In 1895, the Committee published a set of directions on the essential points to be observed in wooden house construction so as to make it better able to stand earthquake shocks. An English translation will be found in the E. I. C. Publ., No. 4, pp 1-5, (with 23 figs). The chief faults in ordinary Japanese wooden construction are the weakening of pillars by being very much cut into, and the want of cross ties and struts, so that very often the whole building suffers simple shearing [see figs. 43, 45,]. Some models, illustrative of the above mentioned essential points, were made, one of which was sent to Shōnai, the district damaged the year before. [I here give photographs of three of these models.2)]

Besides these small models, two wooden earthquake-proof houses were constructed, one in Nemuro, and one in Fukagawa, Tōkyō. Nemuro was chosen, because it was one of the most

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1) Omori: Motion of a Brick Wall produced by Earthquakes; E. I. C. Publ., No. 12.

2) An account of these models is given in the E. I. C. Hō, No. 13.

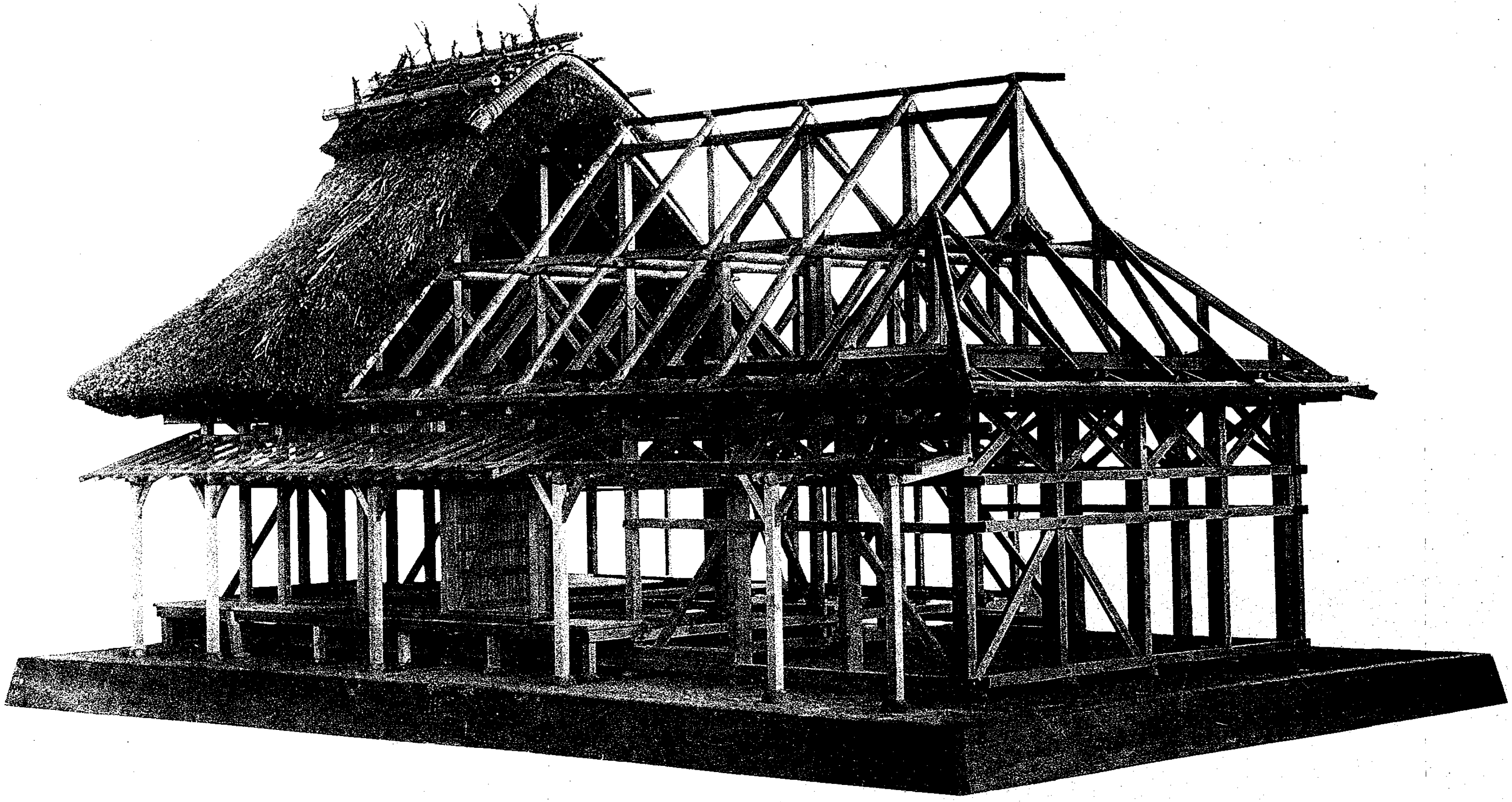

Fig. 48. MODEL OF A FARMER'S COTTAGE.
Showing the essential points of construction recommended by the E. I. C.

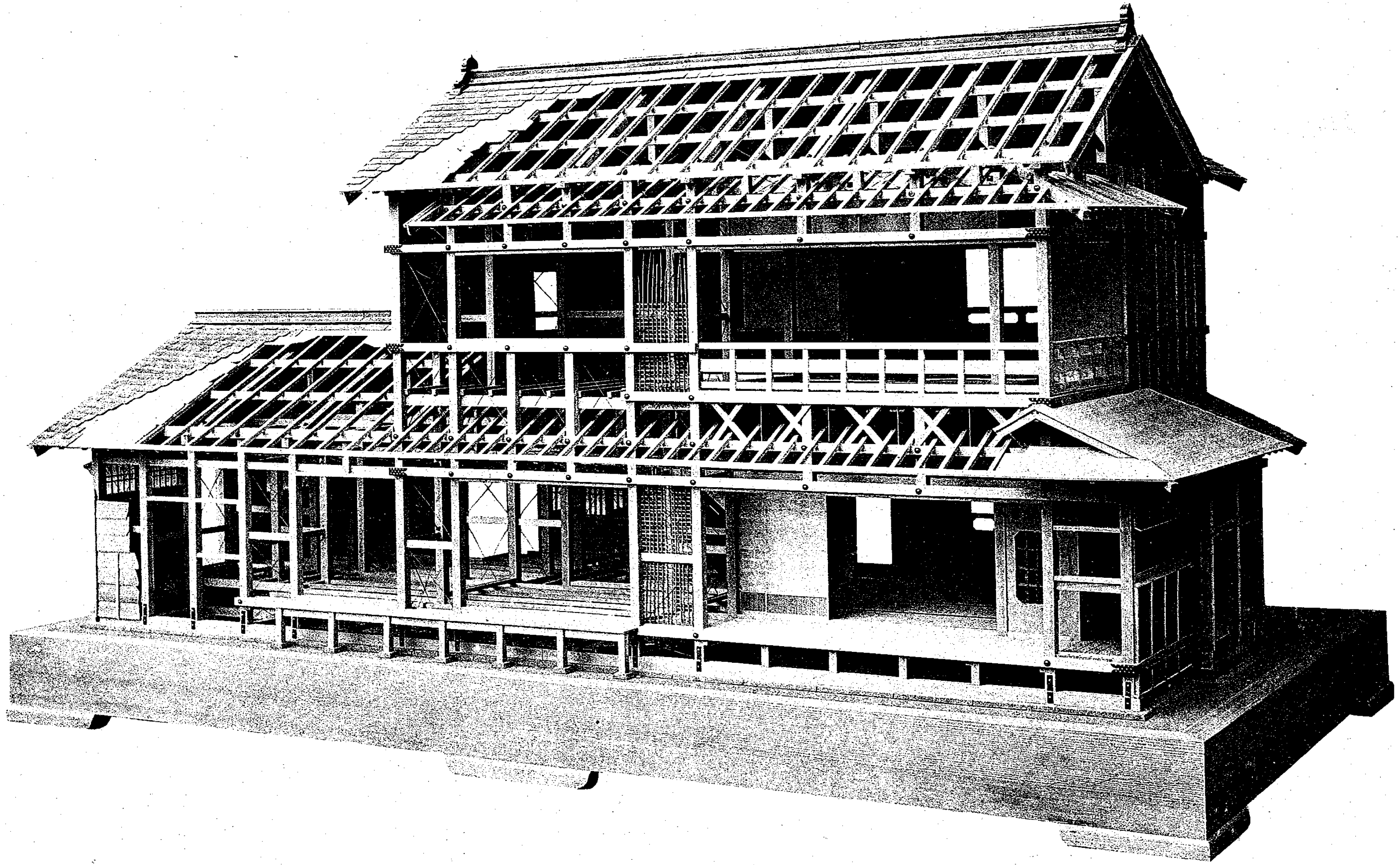

Fig. 49. MODEL OF AN ORDINARY DWELLING HOUSE.
Showing the essential points of construction recommended by the E. I. C.

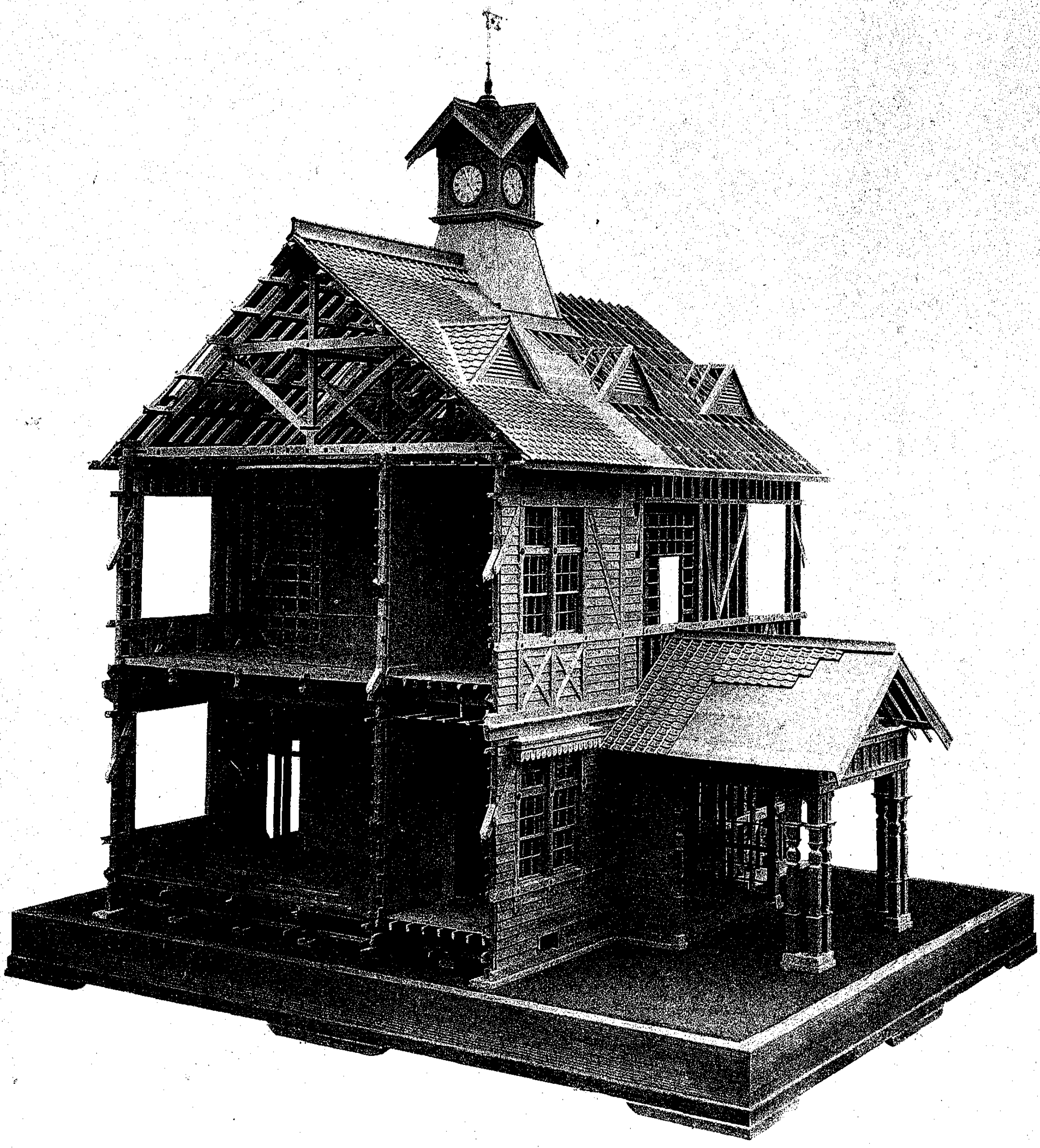

Fig. 50. MODEL OF A PUBLIC BUILDING.
Showing the essential points of construction recommended by the E. I. C.

shaken spots in the extreme north; Fukagawa was chosen on account of the soil there being of soft alluvial mud, so that it was likely to be well shaken; it serves as one of the stations of the Seismic triangulation [see Art. 64].[1]

Chimneys.

111. Much damage to chimneys, especially factory chimneys, having been caused by the great Mino-Owari earthquake of 1891, and Tōkyō earthquake of 1894, a great deal of attention was called to their construction. The E. I. C. made some suggestions directly after the Tōkyō earthquake, as to immediate steps to be taken in their repair and construction. Prof. Mano's reports on damage to factory chimneys in Ōsaka and Tōkyō caused by the destructive earthquakes of 1891 and 1894 [E. I. C. Hō., Nos. 5, 14.] are valuable contributions to this subject.[2] The members of the Committee have availed themselves of every opportunity to collect materials necessary for the scientific treatment of the subject. A few of the experiments made are reported in the Hōkoku and in the publications.[3] The chief object in these experiments was to find out the nature of their vibrations, for on that, of course, will depend the seismic stability of these structures.

The Shaking Table.

112. For the application of seismology to construction in

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[1] For details of construction of these houses, see E. I. C. Hō, No. 13.

[2] See also Omori, Seismic Experiments on the Fracturing and Overturning of Columns, E. I. C. Publ., No. 4, p. 117.

[2] Omori: Note on the Vibration of Chimneys; E. I. C. Publ., No. 12, with 5 pls; Mano and Tanakadate: Note on the Vibrations of a Chimney; E. I. C. Hō., No. 21, with 9 pls.

earthquake countries, it is necessary, besides the observation of the damage due to actual earthquakes, to investigate experimentally the effects of artificially produced movements on various models of construction, the ultimate object being the calculation of the seismic stability of given structures and the finding out of the forms best suited to withstand earthquakes.

For this purpose artificial earthquake motion was produced by means of a *shaking table*, designed by Professors Mano and Inokuty, which consisted of a stout wooden floor properly mounted on strong supports, and which can be made to move with independent horizontal and vertical simple harmonic motions by means of steam engines.[1] As the maximum ranges of motion of the table amounted to 150 mm. and 90 mm. respectively in the horizontal and vertical directions, and as the period can be made as small as 0·2 sec., movements much more destructive than those whick took place at Nagoya or Gifu on the occasion of the great Mino-Owari earthquake can easily be produced.

Some preliminary experiments were tried with small models of wooden structures made for the purpose, but soon it was found advisable to begin with simple elements of construction ; and also for the reasons stated in Art. 109 as well as for simplicity, motion was confined to the horizontal only.

Fracturing and Overturning of Columns.

113. In 1898-99, Prof. Omori made a series of experiments, fracturing some 24 brick columns and overturning numerous other columns, by placing them on the above table and

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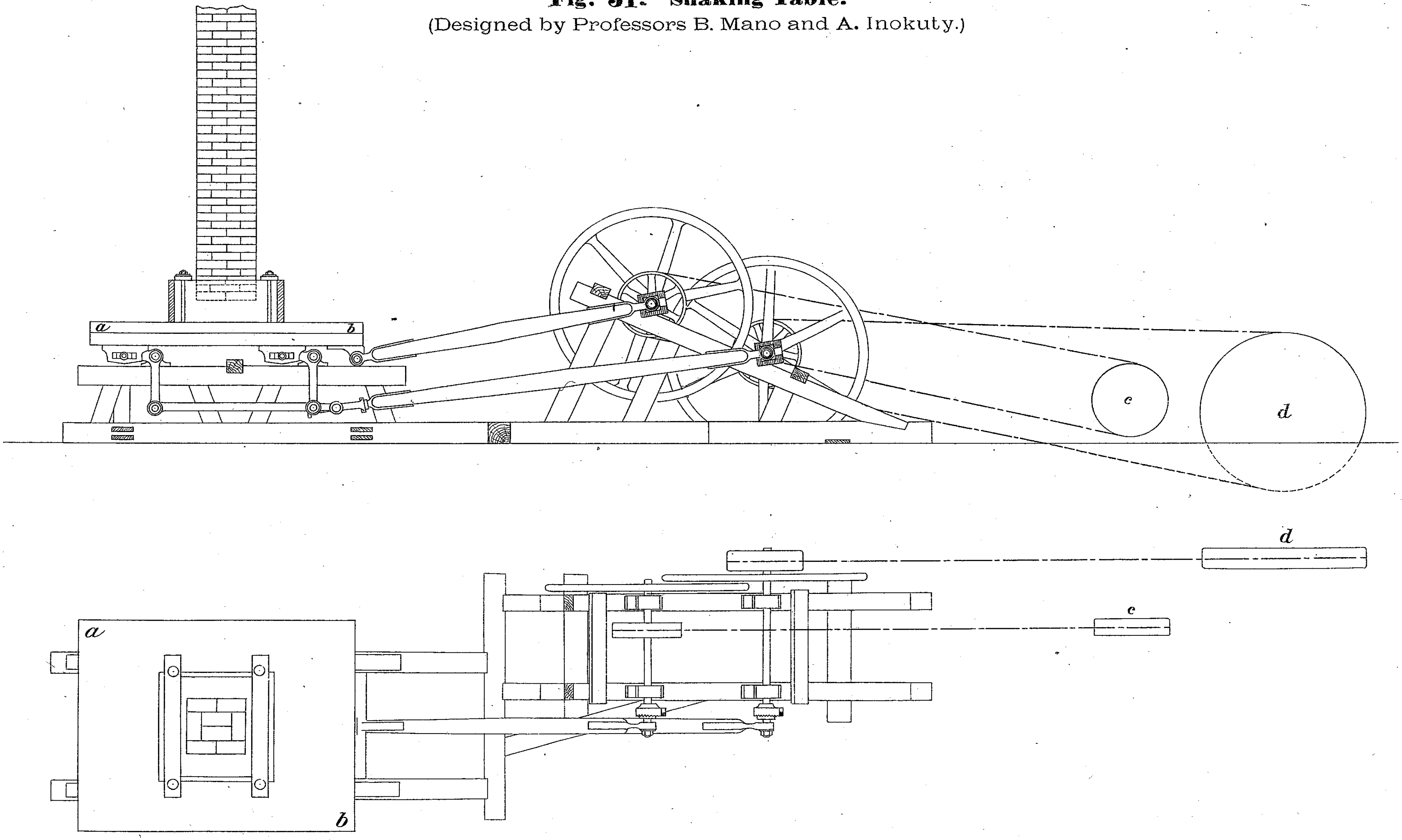
[1] Mano : Appareil pour l'Étude théorique des Tremblements de Terre ; E. I. C. Publ., No. 3, pp. 85-86. Also see E. I. C. Hō, Nos. 2 and 21.

Fig. 51. Shaking Table.
(Designed by Professors B. Mano and A. Inokuty.)



a b is the shaking table, which can be moved horizontally and vertically by means of the two steam engines ***c*** and ***d***.

shaking them; the largest column had a height of 1810 mm. and a cross section of 233×233 mm. A second series of experiments was carried on in 1899-1901, in which about 80 solid and hollow brick columns were fractured; of these the largest was about 2 m. high and had a cross section of 48×46 cm. Other experiments on the sliding and overturning of numerous columns were also made. The results of the first series are given in the E. I. C. Publ., No. 4, pp. 69-141, or Hōkoku, No. 28; the full report of the second series has not yet appeared.(1)

The practical importance of the conclusions that may be deduced from these experiments will be at once evident, when we consider that they will apply approximately to bridge piers and chimneys : I can here only give a very brief outline of them.(2)

114. *For fracturing experiments,* the brick columns were each firmly fixed to the shaking table at the base, its top being free. The fracturing process consisted in moving the table simple-harmonically within a certain range of motion. At first the motion of the table was slow, but it was gradually quickened till the period reached a certain value; when the acceleration of motion became sufficiently great, and fracture of the column took place generally at or near the base. The column was thus broken only by its own inertia. The motion of the shaking table was automatically recorded, while the fracture of the column was carefully watched and its exact moment electrically recorded. The intensity of the motion, which caused the fracture, was then calculated from the diagram and compared with the theoretical value of the

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1) For an account of similar experiments on a small scale, by Profs. Milne and Omori, see Seism. Jour. Japan, Vol. I.

2) In this connection, see also Omori, On the Overturning and Sliding of Columns (caused by earthquakes). E. I. C. Publ., No. 12, pp. 8-27, or Hō., No. 32.

seismic stability of the column.

The amplitude of motion of the shaking table varied between 39·7 mm. and 128 mm., and fairly represented the motion likely to occur in strong and some destructive earthquakes. Further, as the period of the shaking table varied between 0·23 sec. and 0·89 sec., the maximum acceleration varied between 1570 mm. and 21,300 mm. per sec. per sec.; the motion may therefore be regarded as giving the intensity to be expected in any great earthquake. As however a few short columns could not be broken even with the most violent motion of the shaking table, we may reasonably conclude that *simple structures*, like columns, walls or bridge piers, can, when properly constructed, resist any destructive earthquake motion. All the other brick columns experimented upon were broken near, or at, the base; the columns being thus seismically weakest at their base, as is also theoretically evident.

As the brick column is fractured always at a joint, its seismic stability may be increased by using a good mortar, until the strength of the joint becomes equal to that of the bricks themselves.

One of the chief objects of the fracturing experiments was the comparison of the actual intensity of motion of the shaking table with the calculated values of the seismic stability of the columns. The intensity, or the maximum acceleration A, of the shaking may be calculated from the amplitude and period of the shaking at the moment when the column was fractured ; these two quantities being directly measured from the diagrams. On the other hand, the seismic stability, or the least value of the acceleration a, capable of fracturing the column, may be calculated from the thickness, area and form of section, height of centre of gravity of the portion fractured, and the tensile strength of the joint.

In the fracturing experiments so far made, the agreement between the quantities A and a was fairly satisfactory. Thus in a group of the experiments, the mean values of A and a were respectively 8610 and 8670 mm. per sec. per sec.

115. For given values of height and external dimensions, a hollow column has a greater seismic stability than the corresponding solid one; the sides or walls in the former column being sufficiently thick and rigid for it to be regarded as a single structure. In the case of columns with very thin walls, a slight irregularity in the joint may cause them to be fractured at accelerations much lower than those given by the theoretical formulae. Besides, with very thin columns, the mortar joint can not be made sufficiently strong, the adhesion between mortar and brick being perfect only along the middle zone of the joint. Similarly it has been found that, in cases of solid columns, the adhesion is not perfect along the edges of the joints adjacent to the free sides of the columns. These considerations indicate the danger of making a column or wall too thin. It seems, however, that the *principle of hollow column* may, with advantage, be applied to structures of large dimensions, such as the piers of bridges, in which the marginal effect would be trifling.[1]

116. *Overturning experiments* were made principally in connection with the determination of the intensity of motion of destructive earthquakes. Consequently the dimensions of the columns employed in the experiments have been of magnitude comparable to those of the stone lanterns, tomb-stones, etc., observed in actual cases.

Of the 42 columns experimented upon, two were iron pipes,

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1) F. Omori: Notes on Applied Seismology, I. Verhandlungen der 1. internationalen seismologischen Konferenz, p. 398.

8 solid or hollow brick columns, 18 hollow columns or boxes of wood, and the remaining 14 solid columns of wood. The height of the columns varied between 1150 and 242 mm. and the dimension of the section between 300^2 and 90^2 mm.

The columns were put on the shaking table and overturned by giving proper movements to it. The shaking intensity deduced from the diagram of motion of the table was then compared with the theoretical values of the acceleration necessary for overturning the columns. In the experiments, the range of motion of the shaking table varied between 29·5 and 120 mm. and the period between 0·4 and 1·47 second; the maximum acceleration of motion varying between 750 and 10,700 mm. per sec. per sec. A wooden hollow column (242×242×484 mm.), however, could not be overturned even with the utmost intensity of motion at our disposal, which fact shows the difficulty of overturning of certain stable objects in earthquakes.

The overturning accelerations was found to be independent of the nature of the material of the columns.[1]

Vibrations of Bridge Piers.

117. Besides these experiments with small columns on a shaking table, and with some real chimneys, there is another method of investigating the nature of movements of such structures: namely, *to measure the vibrations of railway bridge piers caused by passing of trains over them.* This investigation is evidently important not merely in earthquake and typhoon countries in connection with the determination of their strength in resisting earth-

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[1] Omori: Seismic Experiments on the Fracturing and Overturning of Columns; E. I. C. Publ., No. 4, p. 137.

quake shocks and wind pressures, but as a general engineering problem.

The measurement was made by means of Prof. Omori's *Vibration measurer*, which is a seismograph slightly modified to suit the circumstances of the case. It consists of a helical spring vertical motion seismograph of the Gray-Ewing type, having a multiplication of 2, and a pair of horizontal pendulum seismographs, in which the weight of the bob is about 2 kg., and the distance between the two axes is 20 cm., having a multiplication of 1·5. The record is taken with ink on a band of paper wound round a drum driven at a rate of 12 to 25 mm. per sec., the time being measured by a small pendulum. The motion of a pier is thus recorded in three components, namely, the vertical, the transverse (or normal to the face of a pier), and longitudinal (or parallel to the face).

A vibration measurer for vertical component and that for a horizontal component are among the exhibits of the E. I. C. at this Exposition.

118. A preliminary series of experiments was carried on by Prof. Omori in 1901, on six different piers of four single track railway bridges in Central Japan. The results are reported in the E. I. C. Publ., No. 12, from which I make the following abstract.

The vertical vibration was always very small, while the transverse and longitudinal vibrations were usually well pronounced, their amplitudes being nearly equal to each other; the periods of the vertical and longitudinal vibrations were nearly constant, the mean values being 0·41 and 0·85 sec. respectively. These are probably not the periods of the true elastic vibrations of the piers themselves, but are rather those of the rocking motion of the latter due to the vertical and transverse vibrations of the 200 feet girders which rest upon them. The maximum pier motion was 0·15 mm. for the vertical, and 1·2 mm. for the longitudinal component.

The periods of the transverse, or real elastic, motion of the different piers varied between 0·22 and 0·47 sec.; the maximum range of motion varying between 0·1 and 1·3 mm.

From what has been said above, it is evident that the periods of vibrations of the bridge piers are roughly speaking between 0·2 and 0·9 sec., that is to say, not very much different from the periods of motion in ordinary weak and strong earthquakes. At the time of a destructive earthquake, the motion of the piers would be much greater than that caused by ordinary railway traffic and the period may become upward of 1 sec. As, however, the period of destructive earthquake motion is generally between 1 and 2 sec., we may conclude that the bridge piers are likely to be fractured at the base.

In the case of the Ibi-gawa bridge (near Kuwana) the movements of the piers caused by *strong winds* were nearly the same as those due to the actual passage of the trains. In very violent storms, the motion would be much greater and the range of the transverse and longitudinal vibrations of such piers may, when coupled with those produced by the passage of a train, amount to a few mm.

Iron frames. The two piers, Nos. 4 and 5, of the Ibi-gawa bridge (near Kuwana) are nearly alike, except that the former has elliptical iron frames embedded in the well. The motion of the No. 4 pier was, however, not less than that of the other. This seems to show that iron frames, unless very strong, have no sensible effect on the vibrations of large masonry columns in which they are embedded.

A striking fact is that the motion of a pier does not always depend simply on its height above the well. Thus the motion of the pier of the Kizu-gawa bridge, whose height was 60 feet, was markedly smaller than that of those of the Tone-gawa (near Toride) and the Ibi-gawa (near Kuwana) bridges, although in the cases of the two latter bridges the heights of the piers above the river bed were only about 20 feet. The motion of the pier of the Tone-gawa bridge (near Maebashi), whose height is 40 feet, was also very small. These peculiarities are obviously due to the fact that the river beds of the Kizu-gawa and the Tone-gawa (near Maebashi) are hard, while the beds of the Ibi-gawa (near Kuwana) and the Tone-gawa (near Toride) are muddy and very soft. In other words, the piers with solid foundations are rigid; while those, whose foundations are weak, are very shaky.

From the above it is evident that a pier does not, in general, behave as if it were rigidly fixed to the ground at the surface of the latter. An approximate calculation shows, for instance, that one of the piers of the Tone-gawa bridge (Toride), whose well sinking amounts to 64·86 feet, must vibrate about a point in it some 45 feet below the ground surface as centre.

Deflection and Vibrations of Railway Bridges.

119. Another set of experiments to ascertain the effects of shaking on engineering structures was to measure the deflection and vibration of a railway bridge caused by the passage of a train over it. This also is an instance of the application of seismometrical instruments to practical purposes which are useful in non-seismic countries as well; for the determination of the deflection and vibrations of a bridge gives a criterion of the strength of the latter, and accordingly a comparison of the results obtained from a number of differently constructed bridges may lead us to the best form, in which the economy of material is combined with the strength of structure; and besides, these experiments enable us to know the variation of the strength of a bridge with time and load.[1]

120. The instruments used in these measurements were Prof. Omori's *Deflectograph* and *Vibration Measurer*, the latter of which I have already described [Art. 117]. The deflection was measured as a very slow vertical vibration; and the deflectograph is nothing more than the helical spring vertical motion seismograph, of the type described in Art. 44, with some improvements in the construction in order to reduce the friction between parts of the instrument and bring the steady point very near to the state of neutral equilibrium, so as to lengthen the period of the proper oscillation of the pendulum. The springs are suspended from a small cast-iron stand, about 60 cm. in height, fixed to a strong rectangular wooden plate about 30 × 60 cm. in size, on which the record-receiver is mounted. The steady point is the centre of a small horizontal lead cylinder about 1 kg. in weight, which is properly fixed near the end of a horizontal bar about 30 cm. long. With an apparatus of this dimension, the period of free oscillation of the steady mass can be raised, within the limit of stability, to about 12 seconds.

For reducing friction, a mode of attachment of the writing pointer to the steady mass, the same as in Prof. Omori's horizontal pendulum seismograph [Art. 39], is employed. The multiplication was 1 for a 200′ span truss, and 2 for a 100′ span truss or plate girders.

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[1] F. Omori: On the Deflection and Vibration of Railway Bridges; E. I. C. Publ., No. 9.

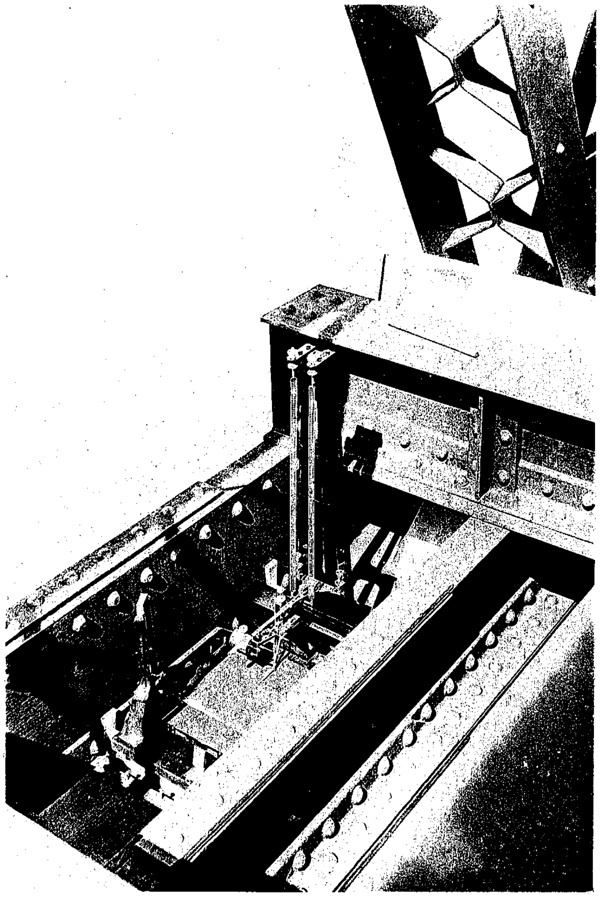

Fig. 52. Deflectograph set up on a Bridge Girder.

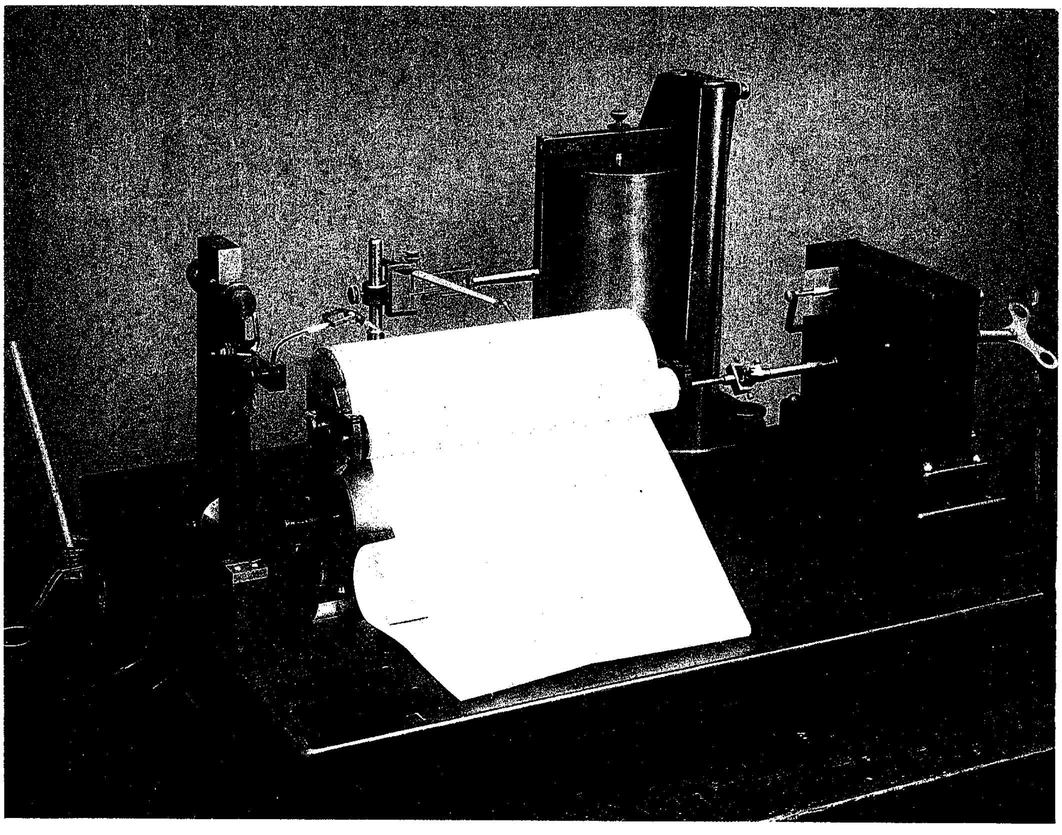

Fig. 53. Horizontal Tremor Recorder.

In some cases the instruments can be fixed most conveniently in the box of one of the bottom chords. But in some trusses and plate girders, we must set up the apparatus within the stringer or the girder itself, below the rails and sleepers, the observer himself getting also therein and waiting the passage of the train overhead. The measurement, which requires no support to be erected from below, is possible even when there is abundant water underneath or when the bridge is high.

Prof. Omori has also devised a simple contrivance, by which the deflection of a bridge can be measured, even in cases when the engine remains stationary on the girder. [This will be described in a future number of the E. I. C. Publ.]

121. An account of the measurements of the deflection and vibration of 11 railway bridges made by Prof. Omori is given in E. I. C. Publ., No. 9, (also in E. I. C. Hō., No. 37); and the results of further experiments on 24 other girders and trusses are given in E. I. C. Hō., No. 45.

Some of the results obtained are as follows:

The 50′ to 70′ plate girders have shown nearly equal amounts of deflection and vibrations as the 100′ Pratt trusses of the Chūbetsu and 3rd Ishikari-gawa bridges.

The vibrations of bridge girders caused by the passage of railway trains are their proper movements and have for a given load a period or periods of motion approximately constant for each of them; the period therefore does not depend on the velocity of the locomotives or on the distances between the wheels of the cars. The effect of the weight of the engine is to prolong the period by a small amount.

That a weak bridge girder has a slow period of oscillation, is well illustrated by the transverse vibrations of the 200′ trusses of the 1st Ishikari-gawa and the Ibi-gawa bridges. Thus the maximum length of the period was 1·06 sec. for the Ibi-gawa and 0·87 sec. for the 1st Ishikari-gawa bridge; and we find the maximum motion of 7·3 mm. for the former bridge and the maximum of 5·0 mm. for the latter.

To illustrate the relation between the strength of a given structure and the period of its vibration, suppose that there are two bridge girders, *A* and *B*, of exactly the same length and construction. If now the rivetting of *A* is better than that of *B*, then the girders may be looked upon as two elastic systems of equal mass, whose elastic moduli are unequal, *A* being more rigid than *B*. Consequently the girder *B* ought to have a longer period and be capable of being thrown into movements of greater amplitude, than the girder *A*.

From the considerations like these it is evident that the deflection and vibration experiments furnish us with criterions of the quality of bridges and like structures; the deflection being the test of strength, and the vibration that of rigidity.

Quite recently Professor Tanabe, of Kyōto Imp. Univ., has also measured the vibration and deflection of the newly constructed Kinogawa bridge. [Bulletin of the College of Science and Engineering, Kyōto Imp. Univ., Vol. I, No. 1.][1)]

122. The vibration measurer can also be made use of to record vibrations in *steamers* caused by the working of the engine, provided there be no great amount of pitching and rolling motion.

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1) Before this, Prof. Ewing obtained statical diagrams of the horizontal movements of a bridge in Scotland, by means of a duplex pendulum seismograph. In Japan, Messrs. Milne and Macdonald measured the vibrations of several bridges on the Tōkaidō Railway, with glass-plate seismographs. The results of these measurements, however, must be received with caution, as the proper oscillation of the steady points themselves seems not to have been sufficiently considered.

These measurements will be useful to engineers for dealing with the vibration problem of steamers. In case of a man-of-war, it would be particularly interesting to measure the vibrations of decks caused by the discharge of guns. Recently measurements have been made by Professors Omori, Terano, Purvis and Shiba, of the vibrations of two torpedo destroyers and a torpedo boat, the results of which will be given in a forthcoming number of the Journal of the Coll. of Engineering of Tōkyō Univ.[1]

123. Yet another practical use of the vibration measurer is to record the vibrations of *railway carriages* and *locomotives.* This application of seismometry to practical engineering was first made by Prof. Milne, whose vibration recorder is, I understand, used by some railway companies for the examination of their lines. This instrument works fairly well and is extremely useful, but there is much friction among its parts, and the steady point has a too great stability, so that its period is often too short. Prof. Omori has made experiments with his vibration measurer, on several lines of railways, and obtained some important results, for which however I must refer you to the E. I. C. Publ., No. 15, or the Hōkoku, Nos. 40 and 42. Dr. Imamura has used the same vibration measurer for horizontal components, combined with Prof. Tanakadate's vertical motion seismograph, to measure the vibrations of electric tram cars.

124. I have given several examples of the application of seismographs, sometimes slightly modified in details of construction, to measure various vibrations of structures, &c., not due to earthquakes. It seems needless to add that they have been used to measure vibrations of ground, due to causes other than seismic.

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[1] The measurements of ships' vibrations, which have already drawn the attention of European and American engineers, were before this tried by Herr Schlick and others.

Thus, they were employed by various seismologists to measure vibrations caused artificially by dropping heavy weights or by explosions of dynamite, &c. In some cases, especially in earlier days, the experiments were made to ascertain the nature of vibrations of the ground; later, they were made oftener for practical purposes, for finding the effects of explosions, &c.

125. Lately, a form of Omori's horizontal pendulum seismograph, called Horizontal Tremor Recorder and magnifying the motion from 50 to 70 times, has been employed for measuring the horizontal tremors of the ground or structures caused by the working of a steam engine, steam hammer, dynamo, &c., or by passing carriages and trains. They have been used by the Tōkyō Metropolitan Police in dealing with questions respecting disturbances due to causes above mentioned [see fig. 53]. One of these instruments is among the exhibits of the E. I. C. at this Exposition; a full description will be given by Prof. Omori in E. I. C. Publ., No. 18.

Fig. 54 is a part of the diagram obtained at the Seismological Institute, of the tremors caused by a small oil-engine of 10 horse power working at a distance of about 70 metres. Movements like these are extremely small and insensible, and yet they have often the effect of causing window panes and doors to rattle, bottles on

Fig. 54.

Vibration Caused by an oil engine.

NS Component. Multiplication 39 times.

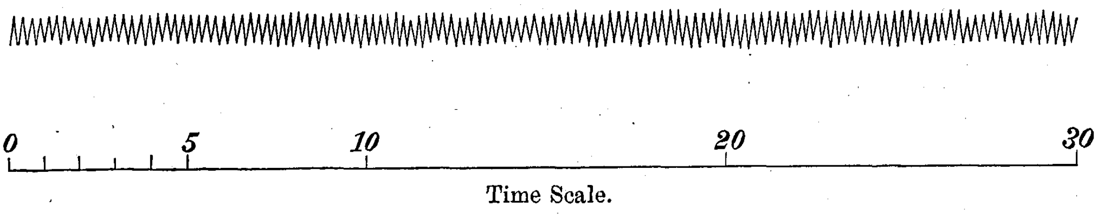

table to shake, suspended articles to swing, &c., thus becoming a source of mystery to people in the neighbourhood.

Determination of Young's Modulus of Brick Columns.

126. In connection with the fracturing experiments, the horizontal pendulums were utilized for measuring Young's modulus of several brick columns, which were about 2 m. in height, their cross sections being 1 brick square.

The experiments consisted in measuring with a horizontal pendulum the terminal deflection angle of a column bent by a known weight. The bending was in several cases carried to the actual breaking; the relation of the stress to the strain remaining very nearly linear throughout. This means that the brick columns behave as an almost perfectly elastic body till they are fractured by bending, a conclusion which has an important signification in connection with the fracture of brick columns. The Young's modulus of several brick columns has been determined in this way. As far as the experiment goes, the highest and the lowest values of the modulus were as follows:—

(highest) $E = 10^{10} \times 4{\cdot}596$ (C. G. S. units)
(lowest) $E = 10^{10} \times 1{\cdot}290$ (,,).

As the period of free vibration of a given elastic body is inversely proportional to $\sqrt{E}$, the period of vibration, for instance, of a chimney, whose brick-work has its $E = 10^{10} \times 1{\cdot}29$ (C. G. S. units) would be about double that of another, similar to it, but made up of brick-work whose $E = 10^{10} \times 4{\cdot}596$ (C. G. S units). This method of experiment is applicable, by increasing the sensitiveness of the instruments, to columns of much greater cross section than those considered above.[1]

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[1] Omori: Notes on Applied Seismology; Verhandlungen der 1. Internationalen Erdbeben Conferenz. p. 382.

CHAPTER VII. CONCLUDING REMARKS.

127. I have sought to give an epitome of the Recent Seismological Investigations in Japan. In our work we have been very much helped by the recent remarkable spell of seismic activity, both on account of the general interest excited, and also by the many excellent opportunities given to scientific men and engineers to study the seismic phenomena. We have now passed through the stage of first rough approximations in our investigations, and are about to enter upon the second approximations. Instead of groping almost in the dark, as in the early days, we now know more accurately what we need, and can better adjust our means to our wants. In many cases we have got the outline and shall have to fill in the details; in others we shall have to extend our results from particular to general, and so on.

128. Moreover, now that our improved seismographs show that earthquake waves are propagated to distant parts of the world, sometimes even more than once round the world, international cooperation has become desirable. The British Association for the Advancement of Science has done well in inviting the cooperation of different countries in seismological work; but something more than a private enterprise, an international organisation with nations contributing, is necessary for a work of this kind; and I am glad to say that an International Seismological Association is now in course of organisation. This association will no doubt concern itself primarily with the investigation of the movements of the earth's crust, sensible and insensible,—the nature and relations of these movements, the path, velocity, and mode of propagation of their waves, and the methods of observing them. The B. A. A. S. laid much stress on making observations with *similar* instruments; but this seems to be by no means so essential: what is important, is rather that the peculiarities of each instrument, such as its proper period, the degree of damping, and the amount of friction between the parts (whether rolling or sliding), &c. should be definitely known and carefully considered in discussing the records.

I am glad to see however that the International Seismological Association will not confine itself simply to the observation of earth motion and to its discussion: it should, either by itself or in cooperation with other bodies, occupy itself with all the principal problems relating to Seismology.

129. It appears that the seismic and volcanic activity is not generally manifested in an isolated manner nor confined to a small part of the world, but rather tends to occur in groups, and often simultaneously in distant parts of the world. Thus, in the nineties, we had, in Japan, a series of large and destructive earthquakes, volcanic eruptions, tsunamis, &c.; during the single month of Sept., 1899, there were 4 large earthquakes in different parts of the world; viz. two in Alaska, one in Asia Minor, and one in Ceram. Are these mere coincidences, or is there some relation between them?

With regard to earth magnetism, it may be that not merely local disturbances but widespread ones also have some connection with seismic activity; it would be as rash to assume that because a magnetic disturbance was observed over a large part of the world, therefore it had no connection with the seismic disturbance at any *one* spot, as that a local magnetic disturbance has a necessary connection with an earthquake near to the disturbance in time and space. It will require a most careful and extensive examination before these relations can be accepted or rejected. It is possible that both of these phenomena as also Volcanic Activity, Variation of Latitude, &c. may be different manifestations of one and the same cause.

I have stated what we have been doing in Japan to find out the relations of the seismic with other phenomena, such as the Seasons, the Changes of Barometric Pressure, the Phases of the Moon, the Changes of Underground Temperature, &c. Among them, some seem to be fairly well established, although their exact determination must await future observations; while others are still doubtful and will require further examination.

There are other physical determinations, such as Gravity, the Elastic Constants of Rocks, and their Thermal Conductivity, the Elastic properties of the Earth's crust, &c., eminently useful to seismologists.

I do not speak of Geology, the importance of which is obvious; what seismologists want to know above all things is the geotectonic nature of the region concerned, for on this must depend its seismic character. In fact, it is as a means of getting an insight into this and the stresses in the earth's crust that the seismologists want the determinations of physical phenomena above mentioned. In a word, pure Seismology is a branch of Geophysics, the Dynamics of the Earth's crust, so to speak.

130. On the other hand, seismology has rendered service to pure physics in several ways, among others, in calling the attention of physicists to the necessity of not overlooking the effects of insensible but by no means very small movements of the earth's crust in delicate physical determinations: Prof. Nagaoka mentions an interesting instance in which the pendulum experiments for the determination of gravity in Tōkyō were affected by insensible movements of the earth, due to a great earthquake originating off the south-western coast of Alaska.[1]

131. With regard to the prediction of earthquakes, it is not to be expected that the E. I. C. should be able to accomplish so difficult a task within so short a time, but there is no reason to assume that by further perseverance in the same and other investigations, we shall not finally arrive at this desired goal.

On the practical side, the E. I. C. has done work of much importance in an earthquake country like Japan. Some of the results however are not confined, in their application, to earthquake countries; the determinations of the vibrations of railway bridge piers, of the deflection and vibrations of girders and trusses, of vibrations of railway and electric cars and of ships, will be of interest and use to engineers in all parts of the world.

132. The study of Seismology is a fascinating one, but to us who are living in a country like Japan, it is not merely of theoretical interest, but of great practical importance. We have so far done our best to advance its knowledge, and we have got over the first stage; and now that the cooperation of the whole world is in a fair way to be established by the organisation of an International Seismological Association, I trust, we shall not be wanting in doing our proper share of the work, large as that share should be; more especially, is it our part to assist in the province of the Macro-seismic Investigation, considering that no other country has such an unenviable preëminence in the matter of earthquake frequency.

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[1] Jour. Sc. Coll., Vol. XVI, Art. 11, p 17.