22 December, 1885.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

(Paper No. 2108.)

"On Construction in Earthquake Countries."

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As the result of observations chiefly made in the main island of Japan, the Author comes to the conclusion that in the whole of the Empire there is on the average at least one earthquake per day. In Tôkiô, where he has resided for ten years, there are usually from thirty to eighty disturbances in a year. Some of these are simply tremors, whilst others have been sufficient to overturn chimneys and to unroof houses. These facts show that the opportunities which residents in Japan usually have for studying the effects produced by earthquakes upon buildings are many. The buildings are of three types. First, ordinary brick-and-mortar structures, such as exist in Europe; secondly, light wooden houses of the Japanese; and thirdly, buildings strongly bound together with cement and iron rods, which are considered to be earthquake-proof. In addition to observing effects which have been produced upon buildings, the Author has, at various times, instituted experiments to measure the relative motion which takes place in different parts of a building when shaken by an earthquake. Other experiments have been made to determine how far earthquake-motion may be cut off from buildings.[1]

The following general description of the observations is divisible into two heads. The first treats of the precautions which may be taken to avoid or lessen the momentum of an ordinary building

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[1] An aseismatic joint invented by Mr. D. Stevenson, M. Inst. C.E., is described in the Paper on "The Japan Lights," by Mr. R. H. Brunton, M. Inst. C.E., in the Minutes of Proceedings Inst. C.E., vol. xlvii., p. 6.

when shaken by an earthquake. This subject has never, hitherto, been investigated. The second treats of the methods best adapted to obviate the destructive effects consequent on that portion of the motion which cannot be avoided, and therefore shakes the building. Before entering on these subjects, an epitome of the facts arrived at, connected with earthquake-motion, is given, having a special bearing on construction.

Generally the earthquakes which have produced effects on buildings in Japan commence with tremors of small amplitude and short period.[1] These appear to be surface-waves or ripples, and they are probably the source of the accompanying phenomena of sound. After the tremors, which usually last ten or twelve seconds, comes the shock. If this has an amplitude of 25 millimetres (0·98 inch), and a maximum acceleration of 500 or 600 millimetres (19·7 or 23·6 inches) per second, brick chimneys are in danger of being cracked. The amplitude and period of a shock are measured from diagrams taken by seismographs. From these quantities, on the assumption of simple harmonic motion, the maximum velocity, which determines the projecting power, and the maximum acceleration or intensity, may be calculated. That this assumption is practically correct has been demonstrated by experiment.[2]

Those who are familiar with calculations respecting the intensity of earthquake-motion will perceive that the methods here pursued are different from those followed by the late Mr. Robert Mallet, M. Inst. C.E., who calculated the overturning, or shattering effects of earthquakes on the assumption that the movement was equivalent to a sudden blow. Although the Author has obtained many hundreds of earthquake-diagrams, and also many from explosions of dynamite and other bodies, he has not been able to obtain the quantities employed by Mr. Mallet. In an earthquake a body is overturned or shattered by an acceleration, f, which quantity is calculable for a body of definite dimensions.

In a diagram this quantity f lies between $\frac{v}{t}$ and $\frac{v^2}{a}$ where v is the maximum velocity, t is the quarter period, and a is the amplitude, or half semi-oscillation.

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[1] Memoirs of the Science Department, Tôkiô Daigaku. Earthquake Measurement. By J. A. Ewing, 1883, p. 63. Report of the British Association for the Advancement of Science, 1884, p. 243.

[2] Transactions of the Seismological Society of Japan. Vol. viii. Seismic Experiments, pp. 1–82.

The phenomenon terminates by a series of irregular vibrations resultant on the first shock, together with other shocks, usually two or three in number, which may succeed each other at intervals of a few seconds. The period of all the vibrations depends partly on the intensity of the disturbance, and partly on the nature of the ground. The concluding vibrations have periods of from 0·2 to 0·25 second. From these remarks it is evident that there may be a disturbance of very large amplitude which would produce no destruction whatever. With regard to the direction of motion, it may be said that at two neighbouring stations it is only the shocks which have similar directions. The motions are generally performed in ellipses, paths like the figure 8, spirals, and a complexity of directions too intricate to define. Small earthquakes, in which there is no pronounced shock, are without any definite direction.

All the motions yet spoken of are horizontal motions. The vertical component is relatively so small that it may usually be neglected. For details of the seismographs, and the tests to which they have been subjected, reference may be made to many papers in the Transactions of the Seismological Society of Japan. In the vicinity of an epicentrum, there is without doubt much vertical motion, but of this the Author has had no experience. It may, however, be concluded that the area of the anaseismic wave is relatively small, and if the effects of the horizontal shock can be nullified, much destruction may be prevented. The first portion of this remark is based upon the following considerations:—

1. The experiments of military engineers with regard to the limiting radius of a crater of explosion.

2. Upon the results of the Author's experiments with dynamite and other explosives, which showed that within 50 feet of an explosion direct waves had no existence, the motion recorded being due to a horizontal surface-wave the vertical component of which was very small.[1]

3. Facts collected by the Author in mining-districts, where one earthquake out of many has not been felt underground, although chimneys were shattered on the surface.

4. On the smallness of earthquake-diagrams taken in a pit as compared with diagrams of the same earthquakes taken on the surface.

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[1] Transactions of the Seismological Society of Japan. Vol. viii. Seismic Experiments, p. 9 *et seq.*

I. Avoidance of Earthquake-Motion.

Experiments have shown that earthquake-motion may be partially avoided either by making a seismic survey of the area on which it is intended to build, and then selecting a site where the motion is comparatively small; or by adopting free foundations, or using deep foundations.

Seismic Survey.—During the last eighteen months the Author has had at and near his house a series of earthquake-stations, none of which were more than 800 feet apart. The instruments at these different stations were all placed in similar positions, and fixed on the heads of stakes level with the surface of the ground. The depth to which the stakes were driven was about 3 feet. When these instruments are placed side by side they give results practically similar. To reduce whatever slight errors might have been due to the instruments, they have been, from time to time, exchanged between the different stations. Four instruments have been placed on soft ground; one is within a few feet of marshy ground; another, also on soft ground, is at the foot of a slope about 6 feet high, rising up to ground which is hard and solid. The remaining stations, with the exception of one which is in a pit, are situated on high, dry ground, upon which there are several heavy brick structures. At the time of an earthquake a pendulum is set free to swing across a cup of mercury. At each contact with the mercury a current from thirty-three Daniel cells is sent to each of the stations. At the first contact the current sets in motion at each of them a carriage carrying a smoked-glass plate, upon which the seismograph writes. At every subsequent contact a mark is made upon the moving plate. By this means it is possible, so far as time is concerned, to institute the most minute comparison between the records given at each station. The smoked plates with their records are subsequently varnished and then photographed. As a general statement of the results which have been obtained by these investigations, it may be said that had different observers been placed in this small area, which is only 10 acres in extent, each would have given a totally different account of the same earthquake, both as to direction, amplitude, period, maximum velocity, and intensity. The actual results obtained for a few of the earthquakes which have been recorded are given in Tables in the Appendix, where A, B, C, D, E, F, G, H, and J, refer to different stations. A, B, E, and F are situated on soft ground. C, D, and J are on hard and relatively high ground. G represents the records taken in a house of peculiar construction, and H is the station in a pit. Whether as regards the average results, or particular earthquakes, it will be found that both in regard to the projecting power as measured by the maximum velocity, or the overturning and shattering power as measured by maximum acceleration, relatively high and hard ground is much more suitable as a site for building than soft ground.

The amount of these differences has, in certain cases, been so great, that it might be inferred that in some earthquakes buildings at C and D would remain standing, whilst similar buildings at any of the other stations would suffer serious injury. The ruins left by earthquakes like those of Lisbon and Jamaica led observers to suspect that the amount of destruction in different parts of a city varied with the nature of the underlying rock. The experiments now described have given measures of these variations. They have also shown that these differences may be very great even on a small area where there is no marked alteration in the nature of the soil, and where the existence of such alteration would hardly be suspected from inspection.

Since this discovery the authorities of Tôkiô have discussed the feasibility of making a seismic survey of the whole city, or at least of those portions where it is intended to erect large and important buildings.

Some years ago the Author conducted experiments to determine the extent of the range of motion on high ground as compared with that experienced on low ground. The result obtained at Tôkiô showed that there was least motion on the hills. This rule appears to be reversed at Yokohama.

Free Foundations.—Mr. Mallet in his introductory sketch to Palmieri's "Eruption of Vesuvius in 1872," speaking of the Japanese lighthouses, says that he was consulted by Mr. Thomas Stevenson as to the general principles to be observed in their construction; "and those edifices have been constructed so that they are presumedly proof against the most violent shocks likely to visit Japan; not, perhaps, upon the best possible plan, but upon such as is truly based upon the principles I have developed."[1] This quotation probably refers to the so-called aseismic tables which carry the lamps. These are tables resting on spheres. Although the tables may have much to recommend them, yet, owing to the ease with which they were moved

[1] "The Eruption of Vesuvius in 1872," by Professor Luigi Palmieri, with notes, &c. By Robert Mallet, p. 43.

by causes other than earthquakes, they have one and all been dispensed with. The only structure standing on balls with which the Author is acquainted is a small building which he erected as an addition to his own house about two years ago. In a report to the British Association for 1884 he described it as follows:—"The building, which measures 20 feet by 14 feet, is constructed of timber, with a shingle roof, plaster walls and ceiling of laths and paper. The balls rest on cast-iron plates with saucer-like edges fixed on the heads of piles. Above the balls and attached to the building are cast-iron plates, slightly concave but otherwise similar to those below. From the records of instruments placed in the building, it would appear that at the time of the earthquake there is a slow back and forth motion, but that all the sudden motion or shock has been destroyed. Thus far the building, or rather its foundations have proved successful in eliminating the destructive element of motion."[1]

The balls referred to were 10-inch shells. Although the device somewhat mitigated the effects of earthquakes, the motion produced by walking, by the wind, and by other causes, resulted in effects much more serious than those due to ordinary earthquakes. To increase the rolling friction the Author next employed 8-inch shot, and after that 1-inch shot. The last attempt was to support the building at each of its six piers upon a handful of $\frac{1}{4}$-inch cast-iron shot resting on flat plates. By this means friction has been so much increased that the building stands solidly, and unless its free foundations were pointed out, their peculiarities would not be noticed. If moved by the application of levers, the building remains in the new position. Its behaviour at the time of an earthquake may be judged by reference to the diagram of the earthquake of the 12th of February, 1884, Plate 3. With the exception of two waves marked A and B, the motion in the chamber was practically nothing; whilst waves equivalent to A and B, together with many which are greater, repeatedly occur in all diagrams taken from the ground in the vicinity of the house. By reference to the Tables in the Appendix the maximum velocities and accelerations inside and outside the house may be compared. Calculating the average values of these quantities, the advantage to be gained by using free foundations is still more marked.

The Author has found by experiment that a shot of the kind used is cracked with a steady pressure of 0·8 ton. If still finer

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[1] Report of the British Association for the Advancement of Science, 1884, p. 248.

shot and in greater quantity could be employed at each pier, the resultant advantages might be increased.

These experiments seem to show that light one-storied buildings, like bungalows, built of wood or iron, may be put up so that sudden horizontal motion of the ground shall be prevented from being transmitted to them, and at the same time they shall resist disturbing causes like those due to wind, equally as well as other buildings.

Deep Foundations.—Experiments with regard to the advantages to be gained by using deep foundations principally apply to heavy structures of brick and stone. The Author regrets that hitherto, owing to the want of means, he has not been able to complete all that he had in contemplation to carry out. So far the results have been as follow:—

At the back of the dwelling-house is a pit 10 feet deep, and about 4 feet wide. At the bottom of the pit is a natural hard earth. Here is placed a seismograph in all respects similar to those at the various stations, and similar to two others on the surface of the ground just above the pit.

The general result obtained from this experiment has shown that at the bottom of the pit motion is always very small. Five different earthquakes have now been recorded in the pit, and the instrument has always been in good working order. In the diagram of the earthquake of the 20th of March, 1885 (Plate 3), which was tolerably strong, it will be seen that the record of the motion in the pit was almost invisible, while that recorded at J, about 20 feet distant, was as 1 to 43. The maximum velocity at these two points was as 1 to 52, and the maximum acceleration as 1 to 82.[1] The importance of this discovery to those who have to build in countries subject to earthquake is obvious. It is the Author's intention to make comparisons between a solid foundation rising freely in a pit, a similar foundation connected with the sides of the pit by brushwood and a covering of earth, and an ordinary foundation. To these may be added experiments on the isolation of a piece of ground by means of excavations.

II. Avoidance of Destruction due to the Acquisition of Momentum.

Having by the application of one or all of the methods now suggested reduced the motion which would be received by a

[1] That these ratios will hold for all other earthquakes is uncertain.

building erected in an ordinary manner, the next point is to indicate principles and to adopt rules by which the effects due to the unavoidable momentum may be reduced to a minimum.

From what has already been stated regarding the nature of earthquake-motion, it seems that stresses and strains applied horizontally have chiefly to be dealt with, and not so much stresses and strains due to gravity. As an illustration of the meaning which it is intended to convey, consider an ordinary masonry arch. For vertically-applied forces this is stable, whilst for horizontally applied forces its stability solely depends upon the adhesion of the material which cements it together. The Author has examined many brick arches which have been cracked by earthquakes in Japan. One of the sets of arches examined formed a connecting-link between heavy brick walls. All of the arches were cracked across their crowns, the cause probably being the horizontal vibration of the walls which they connected. A like set of arches in similarly constructed walls at right-angles to these, and at the same time at right-angles to the principal direction of the shock which had caused the damage, was not cracked. Archways of this description ought at least to be protected by iron or wooden lintels. If archways are indispensable, they should curve into their abutments and not meet them at an angle, the angle being a point of weakness.

The results of an examination of three hundred and thirty similarly built brick structures in the streets of Tôkiô showed that the upper windows of the houses had flattish arches meeting their abutments at an angle. Out of one hundred and twenty-seven cracks in these arches, no less than one hundred and thirteen ran from the angle. Out of two hundred and fifty cracks in the lower arches, one hundred and ten ran down from beams which supported a balcony, and one hundred and forty from some portion of the arch, usually near the crown. Not a single arch was observed to be cracked at the springing when the arch curved into its abutment. Another interesting point was that the number of cracks in walls running north-east to those in walls running south-east was as 1 to 1·3, and it is from south-eastern directions that statistics showed the principal shocks to have originated. This again illustrates the instability of archways to stresses applied horizontally and parallel to their direction of span. As another illustration of a structure weak in resisting horizontal forces, the high wall of a factory may be taken, or a church tower, which contains a series of openings like windows and doors vertically above each other. These openings constitute a line of weakness, and the wall may give way here at the time of an earthquake, as was illustrated in July 1880 at Manila. Openings should not be vertically above each other; they might be in horizontal rows, those in one row alternating in position with those of the neighbouring rows.

Another important rule which must be kept in view is to avoid coupling together two portions of a structure which from their position are likely to have different vibrational-periods.

A remarkable example of the violation of this rule was to be seen in Yokohama after the earthquake of the 20th of February, 1880. A moderately high factory chimney was supposed to require support, and it was therefore connected by an iron band to the side of a neighbouring building. When the earthquake came, the band, instead of giving the chimney support, cut it in two.

Many similar examples of destruction due to difference in vibrational-period could be seen in the chimneys of almost every bungalow, which were shorn off at their junction with the roof. By themselves, either the chimneys or the roofs of the bungalows would have been secure; but when in contact it was evident that they had been mutually destructive. If it is unavoidable that parts of a building having different vibrational-periods should be united, it would seem advisable to connect them by bonds so strong that the various parts thus connected should be constrained to move as a whole. Whilst speaking on this subject a few words may be said about so-called earthquake-proof buildings, for which in America patents have been granted. An example of this type is the City Hall of San Francisco. The chief feature in these structures is that iron or steel rods pass from side to side, and from front to rear, through the walls at each floor, being secured at the ends by washers and bolts. There are also vertical rods. A method of construction very similar to this has been described by Mr. J. Lescasse,[1] and several structures of this kind are to be seen in Tôkiô and in Yokohama.

With the exception of some chimneys on one of these buildings which were shattered in 1880, the others have stood in a satisfactory manner. The same remark may be applied to ordinary strongly-built structures where the complicated system of tie-rods has not been employed. Without doubt the stability of these buildings has been largely due to their strength, which has caused their various parts to vibrate as a whole. Another element which

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[1] Mémoires de la Société des Ingénieurs Civils, 1877, p. 212.

has given them stability has probably been their deep foundations; and had the walls just above the foundations been free at their sides, the experiments previously referred to show that the amount of motion would have been considerably lessened.

Among the experiments made to determine the relative motion of different parts of a building, a few were carried on at the Imperial College of Engineering, which is a heavy solid structure of brick and stone. One set of experiments was made upon the archways of two corridors. These arches have a span of 8 feet 3 inches, a rise of 4 feet 1 inch, and rise from brick abutments 1 foot 11 inches thick, and 7 feet $1\frac{1}{2}$ inch high. The voussoirs of the arch are made of a light grey volcanic tuff, and have a depth on their face of 12 inches. The width of the wall between the arches is 4 feet $6\frac{7}{8}$ inches. Across the springing-line of these arches a light deal rod was placed. One end of this was spiked to the wall: the other end terminated with a fine steel wire, resting on the surface of a smoked-glass plate, placed on a ledge at the top of the other abutment. If these two abutments approached to or receded from each other, a line indicating the range of motion would be drawn upon the smoked glass. A second record of motion was obtained on a glass plate fixed on the middle of the transverse rod, by a pointer hanging vertically from the crown of the arch. The result showed that in a severe earthquake there was sometimes a motion of from 1 millimetre (0·04 inch) to 2·75 millimetres (0·11 inch), the vertical movement of the crown being slightly in excess of the horizontal motion. In slight earthquakes there was either no motion in the arches, or else the different parts of the arch had practically synchronized in their movements.

For a more detailed account of these experiments, together with other observations, the Transactions of the Seismological Society of Japan may be referred to.[1] Another interesting set of observations was made upon the cracks which exist in several of the buildings at the College of Engineering. At the basement of the buildings, which are constructed of a volcanic rock (andesite), the cracks follow the mortar-joints; but when they come to the brickwork above, they run up and down through the whole structure, sometimes along the mortar-joints, but just as often through the bricks. Some of the cracks have a width of $\frac{1}{4}$ inch. Across several of them steel-wire pointers were placed horizontally; one end of the pointer was fixed to the brickwork,

[1] Vol. ii., pp. 32-38.

whilst the other end rested on the face of a smoked-glass plate, in a frame nailed to the wall. In a severe earthquake it seems certain that the difference in phase of the portions of the building at the two sides of a crack sometimes reached 2 millimetres. In slight earthquakes no records were obtained. In addition to these experiments, the ends of a large number of cracks were marked and dated. After a strong shake, many of them were seen to have grown in length. It seems, therefore, that portions of a building which are not likely to synchronize in their vibrational-period ought either to be strongly tied together, or else, by means of joints intentionally left during construction, to be completely separated from each other.

The evil effects consequent on overloading the upper parts of walls, roofs, and chimneys have been mentioned at considerable length by Mr. Mallet in his classical work upon the Neapolitan earthquake.[1] When a chimney with a heavy top is suddenly moved forwards, the upper part, by its inertia, tends to remain quiescent. The result of this, as with all other heavy superstructures, is to cause a fracture between the lower part which has been quickly moved and the upper part which has tended to remain quiescent. In Japan many chimneys have been shattered by these causes. The last chimneys inspected by the Author were those of the British Legation, which partially fell, and were otherwise ruined, on the 15th of October, 1884. These were rectangular in section, half a brick thick, and loaded at the top with a heavy head. Chimneys much thicker, and without the heavy cap, have now been substituted. In Yokohama experience has taught almost every householder to make his chimneys short, thick, and without heavy ornamental copings.

Weighty tile roofs act upon the supporting walls like heavy tops upon chimneys. As an attempt to obviate this, some of the roofs of the Imperial College of Engineering have been built so as to rest loosely on their supporting walls. Had they rested upon layers of cast-iron shot, the increased freedom and independence of the moving walls would probably have rendered them still further secure. In Manila the effects of earthquakes have caused the inhabitants to adopt corrugated-iron as a roofing-material. Walls may be rendered light in the upper parts by the use of hollow bricks. The advantages to be gained by using light superstructures as a means of mitigating

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[1] Great Neapolitan Earthquake of 1857. "The first principles of Observational Seismology." 2 vols. 1862.

the effects of vertical motion are evident. An additional precaution against this movement may be obtained by the use of vertical tie-rods, connecting the upper portion of a building with its foundations.

CONCLUSION.

In the foregoing Paper reference has been made only to general principles; all details of construction have been left to the architect and the engineer. The Author would recommend that ordinary inexpensive dwelling-houses should rise from a solid wall, which itself has a foundation deep enough to reach hard ground. If the ground is soft, and therefore liable to considerable motion, the house might rest upon layers of cast-iron shot not larger than buck-shot. Wooden houses are usually objected to on account of their inflammability and their appearance. If angle- and sheet-iron be used as the building material, internal walls of wood and paper will be required. In a hot climate like Manila three ceilings with corresponding air-spaces are employed. Chimneys may be made of iron tubing. The dangers of fire may be reduced by using two tubes placed concentrically with an air-space between them. Before erecting heavy structures of brick and stone, much might be learnt respecting the nature of the proposed site by instituting a seismic survey. Such buildings ought certainly to have deep foundations, and if the basement had a lateral freedom the motion to which the building is exposed would probably be reduced. With regard to safety dependent on excavations or the contour of the ground, it must be remembered that if a building is only partially surrounded by openings like ditches, moats, steep valleys, and the like, it may be in greater danger than if such excavations did not exist. The reason of this lies in the risk lest the earth-vibration, approaching from the side not cut off, should make the opposite side, where the motion reaches the excavation, a free surface, which would then swing forwards like the last truck in an uncoupled train struck at the other end by an engine. The area of ground capable of being protected by ditches for a given earthquake has not yet been ascertained. Motion which is visible on a level is not visible at the foot of a bank 10 feet deep. At this lower level at the distance of about 100 feet the lost motion, however, reappears.

In the construction of a building the most important principles to be followed are:—First, to provide against horizontally-applied stresses; secondly, to allow all parts of the building with different vibrational-periods either to have freedom amongst themselves, or else to bind them securely together with long steel or iron tie-rods, especially at the floors and near corners, as corners of buildings often suffer in earthquakes. Thirdly, to avoid heavy superstructures. A light iron French roof on the top of a tower may be as ornamental as a heavy coping and roof of stone, and experience has shown that in an earthquake it is much the safer. Although the details of construction have not been entered upon, it is well to point out the insecurity of steeply-pitched roofs, which, if covered with slate and tile, may be destroyed, whilst neighbouring but flatter roofs remain secure.

So far as the Author is aware, the Local Government of Manila is the only one which, in its Building Acts, has made provision against dangers consequent on earthquakes. This was after the disaster of 1880 when the employment of light iron roofs was insisted on. If the Governments of earthquake-shaken countries like Italy and Spain framed building-laws, based on the results of investigations made in Japan and other places, the destruction of life and property so often consequent on these terrible phenomena might be considerably diminished.

The Paper is accompanied by three tracings and a photograph, from which Plate 3 has been prepared.

[APPENDIX.

APPENDIX.

OBSERVATIONS ON EARTHQUAKES AT TÔKIÔ.

1.—*Number of Waves in Ten Seconds.*

1884–1885	A	B	C	D	E	F	G	H	J
March 25 .	22	18							
March 31 .	36	32	23						
April 6 . .	30	25	32						
May 6 . .	32	26	35						
May 11 . .	30	27	35						
May 19 . .	37	33	21						
May 19 . .	22	26							
May 30 . .	28	21							
May 31 . .	31	28							
June 11 . .	32	26	..	26					
October 24 .	36	30							
November 16	34	32	..	38					
November 21	36	35	..	38					
November 27	36	28	..	38					
November 29	26	18	At D too irregular to estimate.						
December 7	..	34	At D too small to estimate.						
December 9 .	24	..	..	24					
December 16	30	28	..	40					
December 23	..	26							
December 30	32	..	..	42	30 or 15				
January 2 .	..	26	..	26	40 or 12	40			
February 1 .	28	20							
February 4 .	30	30	..	..	24				
February 12	30	28	..	..	14	34	72	ripples	
February 27	32	32	..	..	36				
February 28	..	..	..	..	50				
March 12 .	30	26	..	..	18	..	48		
March 20 .	30	30	..	..	14	..	..	12	26
Average .	30	28	29	34	23 or 28	87	50	12	26

OBSERVATIONS ON EARTHQUAKES AT TÔKIÔ—*continued.*

2. *Maximum Amplitude of Waves in Millimetres.*

1884–1885	A	B	C	D	E	F	G	H	J
March 25 .	0·10	0·5							
March 31 .	0·1	0·14	0·05						
April 6 . .	0·3	0·8	0·1						
May 6 . .	0·4	1·0	0·1						
May 11 . .	0·3	0·9	0·1						
May 19 . .	0·07	0·15	0·04						
May 19 . .	0·1	0·2	0·2						
May 30 . .	0·05	0·1							
May 31 . .	0·05	0·1							
June 11 .	0·15	0·25	..	0·1					
Oct. 24 . .	0·07	0·1							
Nov. 16 .	0·25	0·3	..	0·05					
Nov. 21 .	0·1	0·25	..	0·05					
Nov. 27 .	0·15	0·25	..	0·05					
Nov. 29 .	0·2	0·6	..	0·05					
Dec. 7 . .	0·1	0·2	..	0·05					
Dec. 9 . .	0·07	..	..	0·05					
Dec. 16 . .	0·8	1·2	..	0·25					
Dec. 23 . .	..	0·1							
Dec. 30 . .	0·45	..	..	0·2	1·9				
Jan. 2 . .	..	0·25	..	0·05	2·5	0·05			
Feb. 1 . .	0·05	0·07	..	..	0·1	0·01	0·05		
Feb. 4 . .	0·05	0·1	..	..	0·05	0·02	..		
Feb. 12 . .	1·2	0·8	..	..	2·2	0·7	0·5		
Feb. 27 . .	0·1	0·12	..	..	0·05	..	0·04		
Feb. 28 . .	..	..	..	..	0·05	..	..		
March 12 .	0·1	0·3	..	..	0·6	..	0·1		
March 20 .	1·3	1·4	..	..	1·9	..	..	0·035	1·2
Average .	0·37	0·40	0·07	0·09	0·95	0·19	0·17	0·035	1·2

OBSERVATIONS ON EARTHQUAKES AT TÔKIÔ—*continued.*

3. *Period of Largest Wave in Seconds.*

1884–1885	A	B	C	D	E	F	G	H	J
March 25 .	0·72	0·85							
March 31 .	0·30	0·24	0·33						
April 6 . .	0·36	0·61	0·36						
May 6 . .	0·47	0·70	0·36						
May 11 . .	0·35	0·47	0·26						
May 19 . .	0·23	0·36	0·20						
May 19 . .	0·40	0·50	..						
May 30 . .	0·36	0·40	..						
May 31 . .	0·35	0·30	..						
June 11 . .	0·36	0·36	..	0·36					
October 24 .	0·32	0·41	..	..					
November 16	0·47	0·47	0·23	..					
November 21	0·27	0·45	..	0·30					
November 27	0·45	0·36	..	0·20					
November 29	0·36	0·56	..	0·40					
December 7 .	..	0·24	..	0·24					
December 9 .	0·40	..	..	0·40					
December 16	0·45	0·54	..	0·37					
December 23	..	0·40	..	..					
December 30	0·32	..	..	0·18	0·75				
January 2 .	..	0·70	..	0·18	0·9	0·18			
February 1 .	0·45	0·82	..	..	0·5	..	0·18		
February 4 .	0·21	0·30	..	..	..	..	..		
February 12.	0·39	0·39	..	..	0·72	0·42	0·39		
February 27.	0·24	0·28	..	..	0·25	..	..		
February 28.	..	..	..	..	0·18	..	..		
March 12 .	0·18	0·29	..	..	0·64	..	0·31		
March 20 .	0·44	0·53	..	..	1·4	..	..	0·85	0·55
Average .	0·29	0·46	0·30	0·21	0·66	0·30	0·44	0·85	0·55

OBSERVATIONS ON EARTHQUAKES AT TÔKIÔ—*continued.*

4. *Maximum Velocity of Wave in Millimetres per Second.*

1884–1885	A	B	C	D	E	F	G	H	J
March 25 .	0·9	3·7	..						
March 31 .	2·1	3·6	0·9						
April 6 . .	5·0	8·0	1·7						
May 6 . .	5·3	9·0	1·7						
May 11 . .	6·0	12·0	2·4						
May 19 . .	1·8	2·6	1·2						
May 19 . .	1·5	2·5	..						
May 30 . .	0·9	1·5	..						
May 31 . .	0·8	2·0	..						
June 11 .	2·7	4·5	..	1·8					
October 24 .	1·3	1·5	..	..					
November 16	3·5	4·0	..	1·3					
November 21	2·2	3·5	..	1·0					
November 27	0·2	4·4	..	1·5					
November 29	3·4	7·0	..	0·78					
December 7	..	5·0	..	1·2					
December 9	0·1	..	..	0·7					
December 16	0·11	1·4	..	4·2					
December 23	..	1·5	..	..					
December 30	0·9	..	..	7·0	1·6				
January 2 .	..	2·2	..	1·7	1·7	1·7			
February 1	0·7	0·6	..	..	1·2	..			
February 4	1·5	2·0	..	..	..	..			
February 12	1·9	1·3	..	..	1·9	10·1	12·0		
February 27	2·6	2·7	..	..	1·2	..	..		
February 28	..	..	..	..	0·2	..	..		
March 12 .	3·4	6·0	..	..	5·8	..	0·2		
March 20 .	1·8	1·6	..	..	0·8	..	..	0·25	1·3
Average .	4·4	5·3	1·6	1·4	8·7	5·9	7·0	0·25	1·3

OBSERVATIONS ON EARTHQUAKES AT TÔKIÔ—*continued.*

5.—*Maximum acceleration of Wave in Millimetres per Second (Intensity).*

1884–1885	A	B	C	D	E	F	G	H	J
March 25 .	3	27							
March 31 .	44	92	16						
April 6 . .	83	80	28						
May 6 . .	70	81	28						
May 11 . .	120	160	57						
May 19 . .	46	45	38						
May 19 . .	22	81							
May 30 . .	16	22							
May 31 . .	13	40							
June 11 . .	48	81	..	32					
October 24 .	27	22							
November 16	49	53	..	34					
November 21	48	49	..	20					
November 27	27	77	..	45					
November 29	57	81	..	12					
December 7 .	..	125	..	28					
December 9 .	14	..	..	9					
December 16	151	171	..	70					
December 23	..	22							
December 30	180	..	..	245 ?	135				
January 2 .	..	19	..	58	116	58			
February 1 .	10	5	..	..	14				
February 4 .	45	40							
February 12 .	*300*	*210*	..	..	*170*	*145*	*128*		
February 27 .	67	60	..	..	28				
February 28 .	..	..	..	..	80				
March 12 .	115	120	..	..	56	..	40		
March 20 .	249	182	..	..	34	..	..	1·7	140
Average .	75	75	33	35	79	101	84	1·7	140

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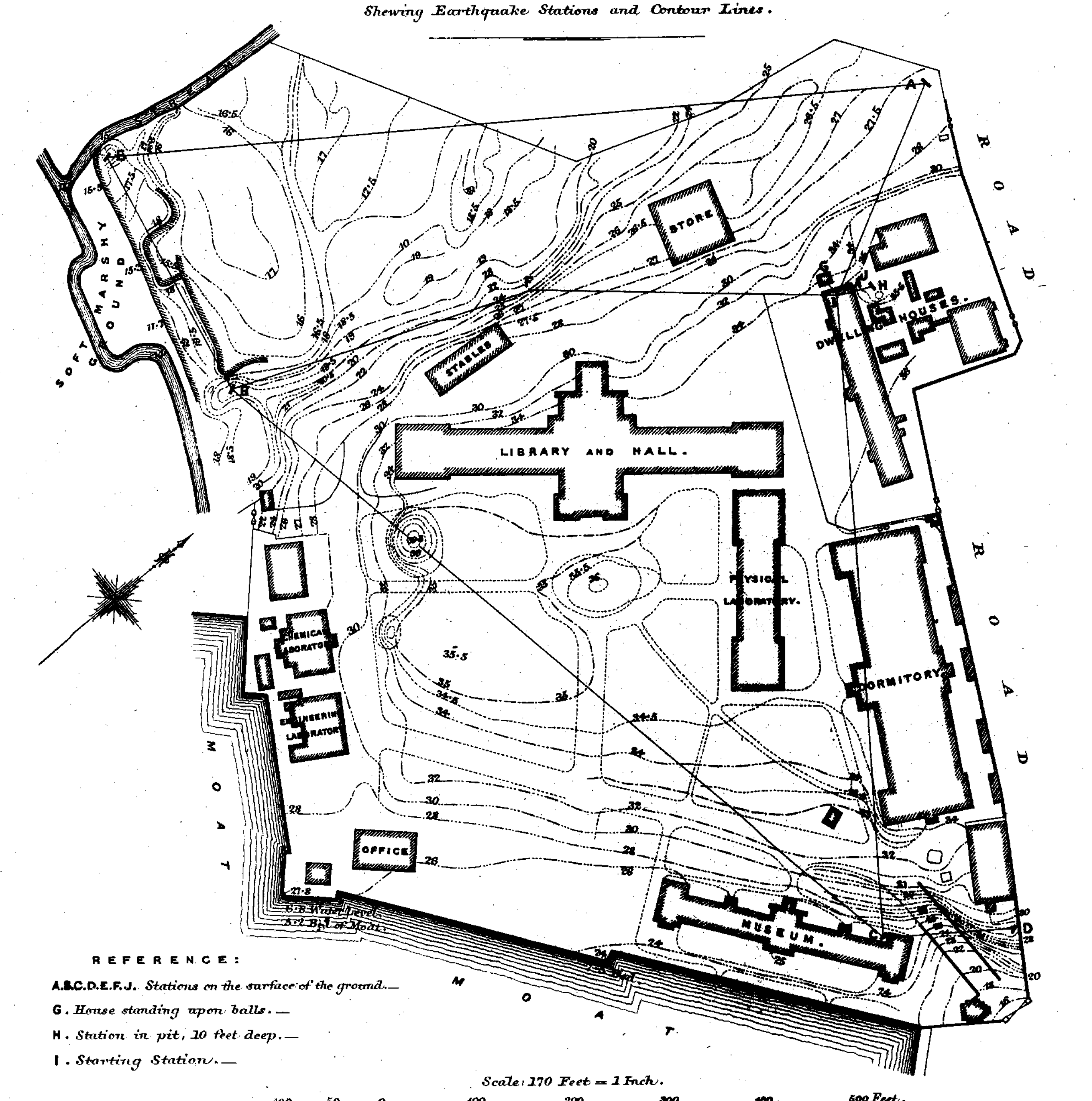

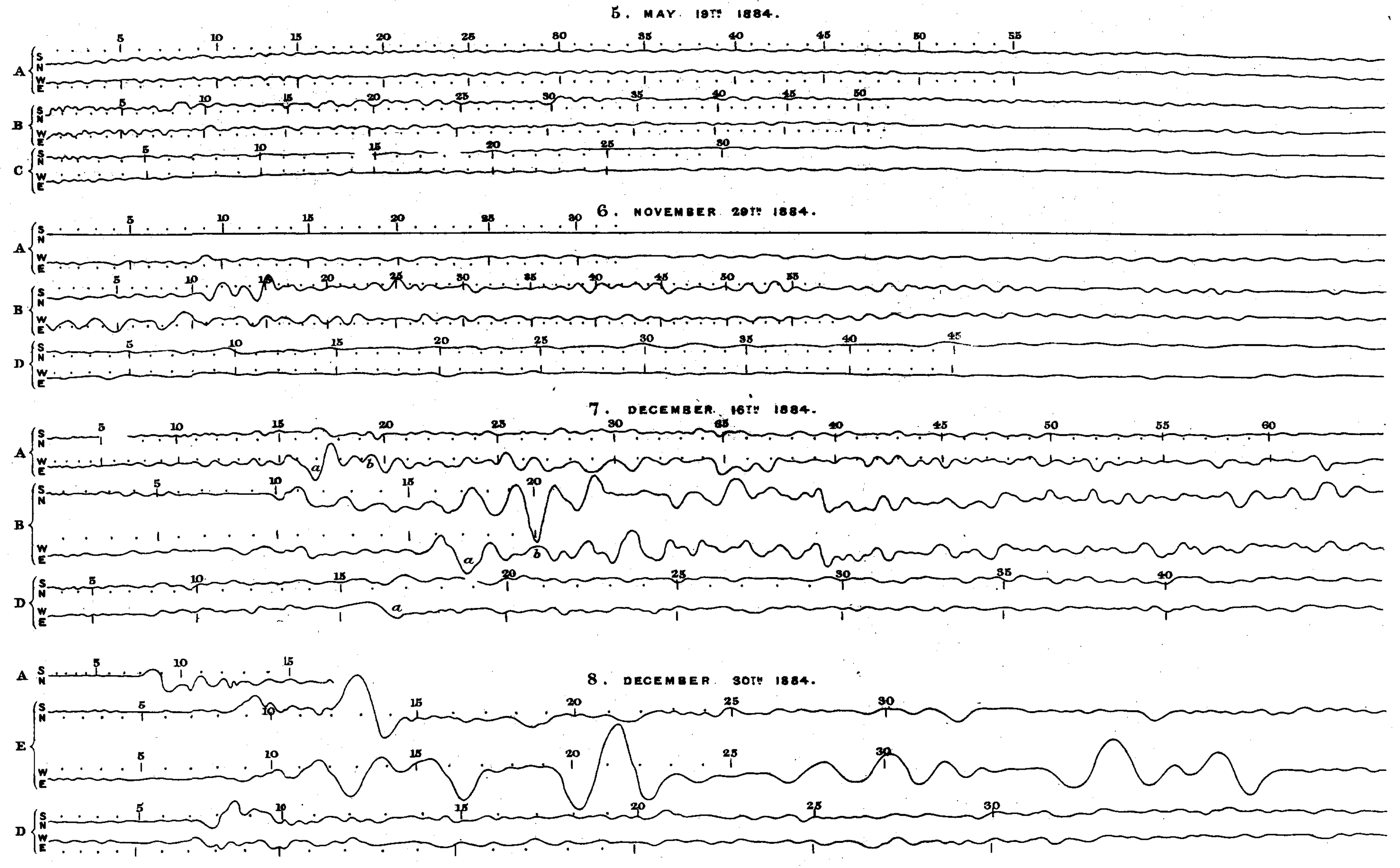

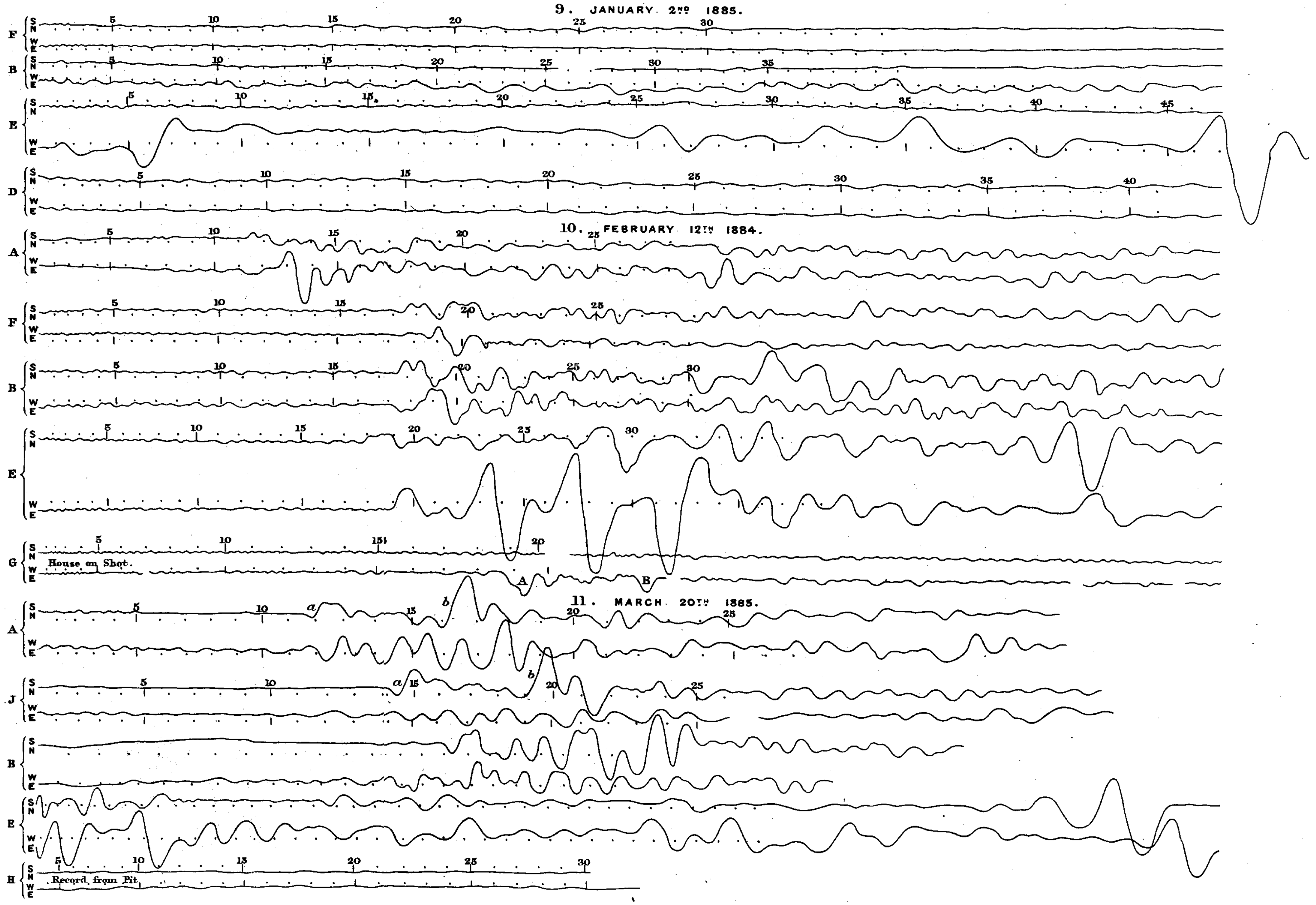

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