ON A SEISMIC SURVEY MADE IN TOKIO IN 1884 AND 1885.

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1. INTRODUCTION.—Description of ground on which the Survey was made. The Instruments, Methods of Observation, Calculations, &c.

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I.—INTRODUCTION.

The following paper is an account of a series of observations made upon earthquakes felt in Tōkyō between March, 1884, and March, 1885. The place of observation was the grounds of the Imperial College of Engineering. These grounds are situated at a slightly higher elevation than the alluvial plain on which a great portion of Tōkyō is built; at the same time they are near to the foot of several of the bluffs which form the edges of the plateau which overlooks the city. Speaking generally, the ground is flat. On its western side it is somewhat marshy, but the remainder of the ground is dry and hard. From the detailed plan of the ground, which was specially surveyed and drawn under the superintendence of my colleague Mr. T. Alexander to illustrate this paper, all details respecting topography, the position of buildings, moats, observing stations, &c., may be readily seen.

On the higher parts of the ground you may sink at least ten feet without meeting with water. From a bore hole half way between stations F and C a vertical section is approximately as follows:—

	feet.
Earth and sand	78
Very hard gravel	2.5
Fine gravel	2.
Sand	6.5
Gravel	10.5
Tuff, a soft volcanic clay rock	—

This last material is probably the commencement or very near the commencement of the stratified tuff formation which, at Yokohama and other places in and near to Tōkyō, is exposed in cliff-like sections.

On the marshy ground, water is met with at a depth of two or three feet.

The area of the ground on which the observing stations are situated is about nine acres.

The general result of the observations has been to show that the amount and character of movement in different parts of the ground has invariably been very different. The instruments employed were bracket seismographs. These wrote the motion of the ground as two components, one being N. and S. and the other E. and W. The pointers giving these records were arranged to write side by side on the surface of a long smoked glass plate. This plate was carried on a light carriage, which at the time of an earthquake was drawn along horizontally beneath the pointers in a direction parallel to their length. All the seismographs were attached to a strong wooden stands strengthened with angle iron. This was fixed on the head of a stake, level with the surface of the ground. The depth to which the stake was driven was in all cases about 2 feet 6 inches. At the time of an earthquake the carriages at all the stations were released simultaneously by a current from 33 Daniel cells. At the time of an earthquake, a contact maker at my house closed the circuit of 2 Leclanché cells, which by means of an electro magnet released a small pendulum which was usually held deflected. At each swing of this pendulum it passed through a small cup of mercury. The first contact with the mercury brought the large battery of Daniel cells into action. At every succeeding swing of this pendulum a current was sent to each of the stations, where by means of electro magnets small levers were deflected. The successive deflections of these levers caused marks corresponding to the swings of the pendulum to be made along the edges of the moving plates. Thirty swings or sixty contacts were made in 22 seconds. Therefore the intervals between the marks on the plate represented .366 seconds of time. By this means it became an easy matter to compare the motion between any of the stations to within $\frac{1}{100}$ sec. of time. For a description of the seismograph and the contact maker see Systematic Observation of Earthquakes, Trans. Seis. Soc., Vol. IV., p. 87-117.)

For the loan of the greater portion of the telegraph wire and posts I am indebted to the kindness of Mr. T. Ishi, Director of the Imperial Telegraphs. For the remainder of the wire, and its erection, I am indebted to Mr. Takeda, Director of the Imperial College of Engineering.

All the instruments were installed so that the plates ran from north to south. In addition to observations made on the surface of the ground, several earthquakes were recorded at the bottom of a pit 10 feet deep, and several inside a house which, at its foundations, rested on cast iron shot. The object of the experiments with the house was to determine a form of foundation to avoid the acquisition of momentum.

This building measures 20 feet by 14 feet. It is constructed of timber with a shingle roof, plaster walls, and a ceiling of laths and paper. The first balls which were used were 10 inches in diameter. They rested on cast iron plates with saucer-like edges fixed on the head of piles. Above the balls, and attached to the building, were cast iron plates *slightly* concave but otherwise similar to those below. The result of this arrangement, which was very similar to an arrangement employed by Mr. David Stevenson for the lamp tables in some of the Japanese lighthouses, was to reduce the *sudden* shock-like movement of an earthquake to a *slow* back and forth motion. Although these foundations greatly eliminated the destructive part of an earthquake disturbance, there was so much motion due to the effects of wind and other causes that they were abandoned. Next I employed 8 inch balls, and after that 1 inch shot. Now the building rests at each of its piers upon a handful of cast iron shot about

$\frac{1}{4}$ inch in diameter. These are between flat cast-iron plates. By this means the rolling friction has been so far increased that the house is astatic and at the same time uninfluenced by ordinary gales of wind. At the time of an earthquake the motion is extremely small, as will be seen by reference to the diagrams.

A few of the latter observations were made at the bottom of a pit 10 feet in depth. At the bottom of this pit the ground is hard and dry. The instrument in this pit was installed similarly to the instruments on the surface.

All the diagrams are tracings taken from photographs of the actual records on the glass plates. The errors in them are due to shrinkage or extension of the paper during the process of taking photographs and slight irregularities due to carelessness in the process of tracing, preparatory to transfer to the lithographer's stone. The shortness of the plates on which the movements were written prevented the whole of the earthquake being recorded. A farther reduction in the length of the diagram has been made by the lithographer. Although in some cases the diagrams may not represent more than the third of an earthquake, there is still quite sufficient given to determine the character of the disturbance.

It may here be remarked that the whole of an earthquake has never yet been recorded. Many of the preliminary tremors have been lost on account of a want of sufficient multiplication in the instrument, whilst concluding vibrations have been lost on account of the frictional resistances of the instrument preventing it recording the slow pulsatory movements which often bring an earthquake disturbance to a close.

Another point to be remarked is that the earthquakes here recorded by no means represent the whole of the earthquakes which occurred during the period of observation. Had I been provided with assistants to smoke plates, photograph, repair instruments and telegraph lines after storms, to make daily visits to the different stations and see that the instruments were in working order, &c., it is possible that double the number of earthquakes which I have recorded might have been successfully captured. Where records are only given for one or two stations it must be assumed that the instruments at the other stations were for various reasons not working. On May 29th, 1884, the instrument at C was moved to D. On December 30th, F and E were started, and the instrument at B was exchanged with that at D. On February 15th, 1885, the instrument at G was started, F was discontinued and moved to J, when it was placed side by side with a similar instrument.

The more important elements which I have recorded for different earthquakes are :—

The number of waves in ten seconds.
The period of some large wave or T.
The maximum amplitude or a.
The maximum velocity or V.
The intensity or $\frac{V^2}{a}$

An inspection of the diagrams, on which about 27 intervals equal 10 seconds, shows that it is possible for an observer to make the number of waves occurring in ten seconds differ, according to the particular interval of 10 seconds which is chosen.

In earthquakes where preliminary tremors are prominent, the number of waves constituting these tremors and occurring in ten seconds may be very large, while the waves in an equal period during the true earthquake disturbance might be small. In the former 60 or 70 waves might be counted whilst in the latter 12 or 14. The waves which I have counted are those of considerable amplitude, which constitute the more sensible part of the disturbance. In many places it will be observed that large waves have small ripples superimposed upon them. If these suprimposed waves are large I have counted them, otherwise they have been omitted. The numbers which I give are therefore only approximate. For instance, where 27 waves are counted as having occurred in 10 seconds another observer may count 26 or 28. From these numbers it is evident that the average period of waves may be calculated.

The period T which I give is that of some large wave for which the amplitude or half semi-oscillation is measured. Here again it is evident that other measurements might be made, but the difference between them and those given would be exceedingly slight.

On the assumption of simple harmonic motion the maximum velocity or $\frac{2\pi a}{T}$ is calculated. This quantity is a measure of the velocity which determines projection.

From the maximum velocity a maximum acceleration $\frac{V^2}{a}$ is calculated, which approximately measures the overturning and shattering power of an earthquake.

For fuller discussion of the experiments which led to the adoption of quantity V and $\frac{V^2}{a}$ as measures of important elements in earthquake motion rather than the degrees of Palmieri, or the "velocities of shock" employed by Mallet, see "Seismic Experiments," Transactions of Seismological Society, Vol. VIII.

II.—RECORDS.

1.—March 25th, 1884.—This was, apparently, a very slight earthquake. From enquiries I found that at least nine out of ten persons did not feel it. Professor Fujioka, sitting upstairs in one of the rooms of the Imperial College of Engineering, observed the weights of a clock swinging and thought that there might be an earthquake. My attention was called to the occurrence of this disturbance by His Excellency A. Davydow, the late Russian Minister, who observed his lamps swinging but did not feel any motion. On referring to my instruments, I found that at stations A and B an earthquake of large amplitude but slow period had been recorded (see diagram). The disturbance does not appear to have been recorded by the instruments at the Imperial Observatory.

An analysis of the diagrams gave the following results :—

STATIONS.

	A.		B.		C.	
	N.S.	E.W.	N.S.	E.W.	N.S.	E.W.
Number of waves in 10 sec....	22		18		—	
Maximum period T	·73		.85		—	
Maximum amplitude (a)	.10		·5		—	
Maximum velocity (V).........	·9		3·7		—	
Intensity $\frac{V^2}{a}$	8		27		—	

Comparing the N.S. waves between the 21st and 25th time intervals as recorded at the two stations, we see that at station A the period is .7 sec. whilst at the latter .64 sec. A point worthy of observation is the great increase in period at the end of the disturbance.

Velocity.—The times of arrival of the waves marked *a b c* at station A before the arrival of the waves *a b* and *c* at station B is .12, .098, and .061 seconds respectively, a mean value for which is .093 seconds. As the distance between A and B is 778 feet, the maximum velocity cannot have exceeded 865 feet per sec. From the character of the diagrams we cannot assume that the disturbance approached A and B in a direction making an angle greater than 45° with the line joining A and B. On such an assumption, after reaching A the disturbance would have 545 feet to travel before reaching B. If this distance was crossed in .093 sec., the velocity must have been about 5,860 feet per sec.

2.—March 31st.—As experienced in my house, the earthquake was long and gentle. For 10 or 15 seconds at the commencement it was so gentle that, had it not been followed by a stronger motion, it would have been difficult to say with certainty that there had been an earthquake. These preliminary tremors are not shown in the diagrams, the plates on which the records were written not having been set into motion sufficiently early.

Palmieri's instrument recorded the shock at 8.22.0 p.m., N.W. 0°.40′, W. 1°.40′, S.W. 1°.20′.

	A.	B.	C.
Number of waves in 10 sec....	36	32	23
Period T	.30	.24	.33
Maximum amplitude a.........	.1	.14	.05
Maximum velocity V	2.1	3.6	.9
Intensity $\frac{V^2}{a}$	44	92	16

The small number of waves observed at Station C is probably due to the smallness of their amplitude, in many places resulting in their coalescence to form a straight line.

In the original plates it would appear that there was a slight similarity between certain waves in the early part of the N.S. motion at stations A and B. It is, however, difficult to recognize similar waves in the diagram taken at station C.

Assuming that similar waves have been recognized there, in three cases the motion reached station B .111, .134, and .106 seconds before reaching station C. The mean value for these intervals is .117 seconds.

The motion reached station A .127 or .050 seconds before reaching station B. The mean of these values is .088 seconds. It is, however, likely on account of the smallness of the diagram at A that there may have been an error in the identification of similar waves.

Assuming the values .117 and .088 seconds to be approximately correct, then the disturbance crossed the observation area coming from the N.W. with a velocity of about 4,270 feet per second.

If, however, we only assume the value .117 seconds to be approximately correct and that the disturbance approached in a N.W. direction (this direction being deduced from the character of the diagrams) we obtain a similar result.

3.—April 16th.—At my house this earthquake was gentle but long. In Igura, which is about a mile distant, it was described as severe. The house resting on 10 inch shells had a long gentle motion corresponding in period to its own motion when set swinging. Palmieri's record was at 0.23.0 a.m. N. 5°, N.W. 3°, W. 3° 10′, S.W. 2° 10′.

An analysis of the diagrams gave the following results:—

	A.	B.	C.
Number of waves in 10 sec..........	30	25	32
Period T..................................	.36	.61	.36
Maximum amplitude a...............	.3	.8	.1
Maximum velocity V	5	8	1.7
Intensity $\frac{V^2}{a}$	83	80	28

Velocity.—In comparing the diagrams from A and B it would appear that the motion had reached B about .13 second before reaching A. This result is based on the examination of 5 different waves each of which appear to be visible at both A and B.

At station C there is only one wave which appears to be reproduced at A (the wave a). Assuming this identification to be correct then the motion at C was felt about 1.2 seconds before being felt at A.

From the first observation the velocity between A and B may have been at the rate of 778 feet in .13 sec. or 5,984 feet per sec.

Taking the observations at A, B and C, in conjunction, then the disturbance advanced from N. 7° W. with a velocity of about 660 feet per second. The probability, however, is that the wave at C did not correspond with the one at A.

4.—May 6th.—At about 5.30 p.m. there was a long earthquake, but not very strong. This I did not feel, as I was then in the garden. A smaller shock, about two hours later, I felt distinctly whilst dining with a friend in Kojimachi.

Palmieri's record was at 5h. 37m. 37s. p.m. N. 3° 20′, W. N.W. 2°.40′, W. 3° 10′., S.W. 4°. There was a second slighter shock at 9h. 0m. 21s. p.m.

An analysis of the diagrams gave the following results :—

	A.	B.	C.
Number of waves in 10 sec....	32	26	35
Period T	.47	.70	.36
Maximum amplitude a.........	.4	.1	.1
Maximum velocity V	5.3	9	1.7
Intensity $\frac{V^2}{a}$	70	81	28

Velocity.—Comparing the waves *a* and *a* at A and B, it would appear that the motion reached A about .07 sec. before reaching B.

Comparing the waves *b* and *b* at B and C, it would seem that the motion reached C about .3 sec. before reaching B The identity of *b* and *b* is, however, very doubtful.

On the assumption that the three identifications at A B, and C are correct, then, the disturbance advanced from the E and crossed the College grounds with a velocity of 2,850 feet per second.

5.—May 11th.—This earthquake was rather long.

Palmieri's record was at 9.45.27 P.M., N.S. 9°, N.W. 8° 50′, W. 6° 30′, S.W. 4° 10′. Duration 1m. 50s. On May 12th at 8.23.47 A.M. there was a smaller shock.

	A.	B.	C.
Number of waves in 10 sec.	30	27	37
Period T.	.35	.47	.26
Maximum amplitude a	.3	.9	.1
Maximum velocity V.................	6	12	2.4
Intensity $\frac{V^2}{a}$	120	160	57

Comparing the N.S. diagrams from A and B, it would appear that *a* had arrived at B about .18 sec. before *a* arrived at A. The waves described at the 20th tick appear to have reached A and B simultaneously. Similar observations may be made on other waves.

6.—May 19th, 12.30 p.m.—This was a long, slight earthquake. A conical pendulum seismograph on my sideboard upstairs showed .3mm. of motion, chiefly E.S.E.

Palmieri's record was at 0h. 28m. 48s. p.m., N. 1° 10′, N.W. 3°, W. 1° 50′, S.W. 0° 10′.

	A.	B.	C.
Number of waves in 10 sec. ...	37	33	21
Period *T*. ...	.23	.36	.20
Maximum amplitude *a*. ...	.07	.15	.04
Maximum velocity *V*...	1.8	2.6	1.2
Intensity $\frac{V^2}{a}$ ...	46	45	38

The small number of waves counted at C is evidently due to their smallness in amplitude, in consequence of which they have coalesced to form a straight line.

7.—May 19th, 11.30 p.m. (No. 2). A slight shock. Palmieri's instrument recorded at 11.35.45 p.m., N. 0° 10′, N.W. 0° 40′, W. 0° 40′, S.W. 0° 50.

	A.	B.	C.
Number of waves in 10 sec. ...	22	26	—
Period T. ...	.4	.5	—
Maximum amplitude *a* ...	.3	.2	.02
Maximum velocity *V* ...	1.5	2.5	—
Intensity $\frac{V^2}{a}$ ...	22	31	—

8.—May 27th.—Palmieri's instrument 11h. 10m. 50s. p.m., S.W. 2° 20′. At my home an exceedingly slight motion was felt for a few seconds. This was followed by a sudden shock, and all was ended. The slight motion was probably the vertical component causing preliminary tremors.

May 29th.—Very slight shock. Instrument at the new Station D, for unknown reasons, did not work. Palmieri's instrument, 11h. 29m. 38s. p.m.

	A.	B.
Number of waves in 10 sec. ...	28	21
Period *T*. ...	.36	.4
Maximum amplitude ...	.05	.1
Maximum velocity *V* ...	.9	1.5
Intensity $\frac{V^2}{a}$ ...	16	22

At the end of the disturbance at B some of the waves have a period of 1.2 seconds and an amplitude of .3 m.m.

9.—May 31st.—Slight shock. Palmieri's instrument, oh. 59m.48s. p.m., N.W. 1° 0′, W. 1° 0′.

	A.	B.
Number of waves in 10 sec.	31	28
Period T.	.35	.30
Maximum amplitude a	.05	.1
Maximum velocity V	.8	2
Intensity $\frac{V^2}{a}$	13	40

10.—June 8th.—At about 10.30 a.m. there was a slight shock, consisting of 3 or 4 quick back and forth movements of small amplitude. This was not recorded at the Observatory by Palmieri's instrument.

11.—June 11th.—A short, sharp shock at about 11 p.m. Palmieri's instrument, 11h. 11m. 02s. p.m., W. 6°.

	A.	B.	D.
Number of waves in 10 sec.	32	26	26
Period T.	.36	.36	.36
Maximum amplitude a	.15	.25	.1
Maximum velocity V	2.7	4.5	1.8
Intensity $\frac{V^2}{a}$	48	81	32

The motion appears to have reached A and D at the same moment. The movement, however reached B about 1¼ ticks (.45 sec.) before reaching A. The identification of similar waves is doubtful. The velocity derived from this is 1,644 feet per second, the disturbance approaching from N. 35 E.

12.—June 14th.—In morning a slight earthquake. Palmieri's instrument, 3h. 29m. 19sec. a.m., N.W. 0° 20′, W. 0° 10′, S.W. 0° 10′.

13.—June 15th.—A slight shock, only just perceptible upstairs. Palmieri's instrument, oh. 6m. 25sec. p.m.

14.—June 18th.—A slight shock at 11h. 19m. 16sec. p.m.

15.—July 2nd.—A slight shock at noon. Not recorded at the Observatory.

16.—September 15th.—There was a small earthquake at 8 a.m. It commenced very gently as a series of tremors lasting

10 or 15 seconds. After this there was a sudden increase in motion. This was followed by a severe typhoon which raged all day. Not recorded at the Observatory.

17.—October 8th.—There was a slight shock in Yokohama at 3h. 46m. 30sec. p.m. At the end of September there were several small shocks. Not recorded in Tōkyō.

18.—October 13th.—At 3h. 16m. 35sec. a.m. there was a strong shock. Palmieri's instrument, N.W. 1° 10′, W. 4° 40.

19.—October 15th.—On this date there was the strongest shock of the year. Plaster fell from roofs and clocks were stopped. One or two chimney's fell. In Tōkyō, Dr. Naumann's chimney at Yamato Yashiki fell. This is close to my house.

Palmieri's instrument, 4h. 21m. 54sec., N. 12° 30′, N.W. 53° 40′, W. 48° 30′, S.W. 95° 10′.

In Yokohama this disturbance was recorded at 4h. 21m. 38s. or 16 seconds before being felt in Tōkyō. Mr. K. Sekiya at the Tōkyō University obtained a record with a maximum range of motion of 42 mm. and a maximum acceleration of 500 mm. per sec. His observatory is situated on the soft alluvium which constitutes the low ground of Tōkyō.

The origin of this earthquake is probably in or near Tôkyô Bay.

20.—October 19th.—About 8.30 p.m. there was a slight shock. At the three stations ripples were just visible.

Palmieri's instrument, 8h. 22m. 47s. p.m. N.W. 1°, W. 1° 40′.

21.—October 24th.—Palmieri's instrument, 8h. 35m. 39s. p.m., W. 1° 20′; duration about 20 sec.

	A.	B.	C.
Number of waves in 10 sec......	36	30	too small to estimate.
Period T..............................	.32	.41	
Maximum amplitude a	.07	.1	
Maximum velocity V.	1.3	1.5	
Intensity $\frac{V^2}{a}$	27	22	

The motion appears to be equally divided between the N.S. and the E.W. components.

22.—November 16th.—I had just taken the reading of a level indicator in the Physical Laboratory, when I observed the pointer of the instrument moving with decided sharp motions about East and West. This movement continued for about 30 seconds, when the motion became more violent, having a range of 30 or 40 millimeters. As the instrument has a multiplication of 80, the true motion must have been about .5 millimeters. The direction of motion was irregular, but chiefly East and West. Sometimes the pointer described ellipses, sometimes it traced a path like the figure 8. After about 6 minutes the forced motion appeared to cease, and the movement was regular, due to a swing of the pendulum. It was 9 minutes before the pointer regained its original position. The change in position of the pointer in this instrument as in two others was about 1 mm. During the disturbance I neither felt a motion or heard a sound. In my own house, however, upstairs, the movement was moderately strong.

Palmieri's instrument, 9h. 51m. 34s. a.m. N. 2°.30′, N.W. 0°.20′, W. 3°.40′, S.W. 0°.10′.

At Hakodate there were two shocks, one at 1.30.20 and the other at 2.15 p.m. The first lasted 40 sec., and the second 3 sec. The first disturbance was sudden and violent. Clocks stopped; articles were thrown down. Warehouses cracked. Altogether, it was one of the most severe shocks felt during recent years.

	A.	B.	C.
Number of waves in 10 sec.......	34	32	38
Period T..............................	.47	.47	.23
Maximum amplitude a............	.25	.3	.05
Maximum velocity V..............	3.5	4	1.3
Intensity $\frac{V^2}{a}$	49	53	34

At A the motion was chiefly E. and W. At B it was slightly more N. and S. than E. and W. At D it was slightly more E. and W. than N. and S.

From the times it is evident that the Hakodate disturbances were not the same as the one recorded in Tōkyō.

At about 10 a.m. there were two shocks felt near Yamagata.

23.—November 21st.

	A.	B.	C.
Number of waves in 10 sec.......	36	35	38
Period T..............................	.27	.45	.30
Maximum amplitude a............	.1	.25	.05
Maximum velocity V..............	2.2	3.5	1
Intensity $\frac{V^2}{a}$	48	49	20

At A the motion was chiefly E.W. At B the motion was equally E.W. and N.S. At D the motion was rather more E.W. than N.S.

24.—November 23rd.—About 11 a.m. there was a long, slow earthquake; whilst standing up it was with difficulty perceptible. In the same room, however, those who were seated felt it distinctly. It made a lamp about 6 feet long swing through an arc of about 6 inches.

Palmieri's instrument recorded two shocks, one at 10h. 50m. a.m., and a second at about 9h. 0m. p.m.

At my house I recorded three shocks, one at 10.53.3 a.m., another at 6.35.0 p.m., and a third at 3.00 a.m. on the 24th. Near Sendai all three shocks were felt sharp and strong.

25.—November 24th.—By Palmieri's instrument, 1h. 37m. 53s. p.m., N.W. 3° 0′, W. 8° 45′. In Yokohama the shock was felt at 1h. 37m. 22s. p.m., the duration being 10 sec.

	A.	B.	D.
Number of waves in 10 sec.	36	28	38
Period T.	.45	.36	.20
Maximum amplitrede a.	.15	.25	.05
Maximum Velocity V.	2	4.4	1.5
Intensity $\frac{V^2}{a}$	27	77	45

At A the motion was almost entirely E.W.

At B the motion was equally E.W. and N.S.

At D the motion was rather more E.W. than N.S.

26.—November 29th.—

	A.	B.	D.
Number of waves in 10 sec......	26	18	too irregular to estimate.
Period T..........................	.36	.56	.4
Maximum amplitude a	.2	.6	.05
Maximum velocity V	3.4	7	.78
Intensity $\frac{V^2}{a}$	57	81	12

At A the motion is almost entirely E.W.

At B the motion is equally E.W. and N.S. At one point there is a movement 1mm. towards the S. and. 4mm. towards the W. This gives a motion of 1.1 m. from N. 23 E. to S. 23 W.

At D the slight but irregular motion is slightly more prominent in the N.S. component than in the E.W. component.

The duration at B would be at least 50 seconds.

27.—December 1st.—About 8.15 a.m. there was a slight earthquake.

Palmieri's instrument, 8h. 11m. 55s. a.m., W. 4°, duration 1m. 05s.

	A.		B.
Number of waves in 10 sec.	28	....	26
Period T..................................	.27	....	.27
Maximum amplitude a.	.35	....	.25
Maximum Velocity V..................	—	....	—
Intensity $\frac{V^2}{a}$	—	....	—

28.—December 6th.—During the early mornring a slight shock, say 2 or 3 a.m.

29.—December 7th.—Palmieri's instrument, 4h. 20m. 14sec., W. 1°, duration 18sec. A second shock at 8h. 34m. 07sec., 4° 10′ N., duration 50sec. This second shock was rather strong. The shock was felt at Shinbashi but not at the Club, where many people were dining. These places are within half a mile of each other.

	A.	B.	D.
Number of waves in 10 sec......	—	.34	too small to estimate.
Period T..........................	—	.24	.24
Maximum amplitude a	—	.2	.05
Maximum velocity V	—	5	1.2
Intensity $\frac{V^2}{a}$	—	125	28

During the night there were other shocks, at 9 and again at 10 p.m. At 8 p.m. two shocks were felt at Shidzuoka.

30.—December 9th.—Palmieri's instrument, 10h. 30m. 56s. p.m., S.W. 0° 55′. Duration 47 seconds. At Sapporo it was very severe, being felt about 10 30.0 p.m.

	A.	D.
Number of vibrations in 10 sec.	24	24?
Period T	.4	.4
Maximum amplitude a	.07	.05
Maximum velocity V	1	.7
Intensity $\frac{V}{a}$	14	9

December 16th.—This disturbance was rather strong. Although it did not cause lamps to swing in my house (perhaps owing to the shortness in its period), at a house near the British Legation the intensity was sufficiently great to overturn a lamp.

Palmieri's instrument, 8h. 31m. 9s. p.m., N. 3° 20′, N.W. 3° 20′, W. 5° 30′, S.W. 4° 40′.

	A.	B.	D.
Number of waves in 10 sec.	30	28	40
Period T	.45	.54	.37
Maximum amplitude a	.8	1.2	.25
Maximum velocity V	11	14	4.2
Intensity $\frac{V^2}{a}$	151	171	70

At A the motion was practically E. and W. Principal wave 1.5 W. and .3 S.; this indicates the true motion as 1.5 W. and .3 S.; this indicates the true motion as 1.55 mm. N. 76 E.

At B the motion was equally E.W. and N.S. Principal wave 2.5 N. and .3 W. This gives a true motion of 2.55 mm. N. 7 W.

At D the motion is equally E.W. and N.S. Principal wave .5 S. and .6 E. This indicates true motion of .7 m. from N. 45 W.

Velocity.—Assuming the waves a, a, a, to be similar, then the waves at A and B arrived .084 sec. and .186 sec. after reaching D.

The difference in the time of arrival at A and B is .102 sec.

If the waves *b b* are similar, then the difference in the times of arrival at A and B is .183 sec.

The interval between *a* and *b* at A is 1.139 sec., whilst at B it is 1.277. This indicates that as the motion passed from A to B the waves spread out.

32.—December 21st.—A very slight earthquake was felt at Shinagawa.

33.—December 22nd.—Palmieri's instrument, 10h. 34m. 1sec. a.m. N., 3° 20′, N.W. 2° 10′, W. 2° 10′, S.W. 2°, duration 25sec. At my home the shock was moderate. At Yokohama it was felt in the Settlement at 10.30.38.

34.—December 23rd.—A slight shock. Palmieri's instrument, 9h. 06m. 42sec., W. 3° 0′, S.W. 2° 50′, duration 26sec.

	B.
Number of waves in 10 sec.	26
Period T.	.4
Maximum amplitude a	.1
Maximum velocity V	1.5
Intensity $\frac{V^2}{a}$	22

Some of the waves at the end of the disturbance have a period of ·7 sec.

This was felt all round the Bay, being strong in Kadzusa; with Kadzusa and Awa added, the area disturbed was like that for map 46. Trans. Seis. Soc. Vol. VII., Pt. 2.*

At 10 p.m. a shock was felt at Wakayama in the South.

35.—December 25th.—Palmieri's instrument 9h. 59m. 29sec. p.m. At Takenawa (a suburb of Tōkyō) it was felt sharply.

36.—December 30th.—Previous to this earthquake, instruments were put up at F and E, whilst the instruments at B and D were interchanged.

As felt in my house, this shock was strong.

A duplex pendulum in my drawing-room indicated a N.S. motion. Palmieri's instrument 1h. 4m. 41sec. a.m., N. 6°,

* All maps referred to are in the same volume.

N.W. 6°, W. 4° 30′, S.W. 5° 20′, duration 49sec. There was also a slight motion felt at my house about 10 a.m.

	A.	E.	D.
Number of waves in 10 sec. ...	32	30 or 16	42
Period T.	.32	.75	.18
Maximum amplitude a	.45	1.9	.2
Maximum velocity V	9	16	7
Intensity $\frac{V^2}{a}$	180	135	245

At A only a partial record of the N.S. component was obtained.

At B only a statical record was obtained indicating an amplitude of 1.5mm. N.S. and .8mm. E. and W.

At E the principal motions E. and W. One motion 2.5 to the N., combined with a motion 1.5 to the W., gives a true motion of 2.9 mm. towards N. 30 W.

The largest motion is 3.6mm. to the West.

At D the motion is equally N.S. and E.W.

The preliminary tremors at E. were performed at the rate of 7 per second.

Comparing A and E, we see that although there was a big amplitude at E the intensity was small.

The distribution was like map 51. At the same time there was a shock at Wakayama.

37.—January 3rd, 1885.—Palmieri's instrument, 2h. 31m. 53sec. a.m., N. 0° 50′, N.W. 0° 50′, W. 2° 55′, S.W. 3° 0′.

	F.	B.	E.	D.
Number of waves in 10 sec.	40	26	40 or 12	26
Period T.	.18	.7	.9	.18
Maximum amplitude a.......	.05	.25	2.5	.05
Maximum velocity V....... ..	1.7	2.2	17	1.7
Intensity $\frac{V^2}{a}$	58	19	116	58

38.—January 8th.—Very slight. Palmieri's instrument, 10h. 27m. 45sec., N. 0° 45′, N.W. 0° 35′, W. 0° 30′.

39.—January 17th.—Palmieri's instrument, 10h. 13m. 59sec. a.m., N. 0° 40′, W. 0° 10′, S.W. 1° 0′. There was a slight record at the stations A and B. But although the machines were in good working order there was no record visible at F and E. The disturbance was not felt at my house.

40.—January 17th.—Palmieri's instrument, 11h. 20m. 41sec. p.m., N. 0° 25′, N.W. 1° 0′, W. 2° 0′, S.W. 0° 10′. The disturbance was just perceptible at my house.

At F the motion was barely visible, and this only for 2 or 3 seconds. Amplitude, .05mm. Period, .2sec. Motion chiefly N. and S. The motion at right angles to the bank being cut off.

At B motion extends over 13sec. Amplitude, 1mm. Period, .2sec. Direction chiefly E. and W.

At E.—Amplitude, .2mm. Period, .5sec. The motion continues over 15sec. It is altogether N. and S.

At D.—The motion is extremely slight. Amplitude, .04mm. It is chiefly N. and S.

41.—January 24th.—Palmieri's instrument, 9h. 20m. 04s. a.m., N. 2° 20′, N.W. 2° 40′, S.W. 2° 20′, W. 3°40′, duration 16 sec.

At the house on shot the movement was just perceptible.

	F.	B.	E.
Period	.12	.3	.3
Amplitude	.01	.3	.5
Chief Direction of Motion	N. & S.	E. & W.	N. & S.

42.—February 1st, 1885.—In my house this disturbance was felt as a slow, long earthquake. Not recorded by Palmieri's instrument.

	A.	F.	B.	E.
Number of waves in 10 sec.	28	—	20	—
Period T.	.45	—	.82	.5
Maximum amplitude a	.05	.1	.07	.01
Maximum velocity V	.7	—	.6	1.2
Intensity $\frac{V^2}{a}$	10	—	5	14

Where nothing is mentioned, means that the waves were too small for measurement. The above measurements are all made near the commencement of the disturbance. The instrument in the house on shot indicated a series of very small ripples with an amplitude of .02 mm. Near the end of the disturbance the periods and amplitudes were as follows:—

At A, period .36, amplitude .15.
At E, period .61, amplitude .15.

The increase in period and amplitude in the N.S. component at E on the swampy ground is very noticeable.

43.—February 4th.—Palmieri's instrument, 7h. 52m. 7sec. p.m., N. 1° 20′, N.W. 0° 20′, W. 2° 10′, duration 43sec.

Distribution very similar to map 74. Simultaneously a shock was felt near Nakamura (Station 27).

	A.	F.	B.	E.	House.
Number of waves in 10 sec......	30	—	30	24	—
Period T..........................	.21	—	.30	—	—
Maximum amplitude a	.05	.02	.1	.05	—
Maximum velocity V	1.5	—	2	—	—
Intensity $\frac{V^2}{a}$	45	—	40	—	—

In the above table the omissions indicate that the waves were too small to admit of measurement.

The motion at A and F is chiefly N.S.

At E the motion although chiefly N.S., the E.W. component is also clearly marked. At B the motion is chiefly E.W., with long period waves at the end of the disturbance.

In the house on shot there were some short period ripples indicated.

About 6 a.m. a shock was felt in Shidzuoka.

44.—February 6th.—A stiff shake at 1.34.0. In Yokohama at 1.35.0. The comparison was made by bringing up a watch. Palmieri's instument, 1h. 34m. 57s. p.m., N. 10° 40′, N.W. 8° 40′, W. 7° 0′, S.W. 2.50, duration 57sec. There had been a shock previously at 9h. 40m. 27s. a.m.

45.—February 9th.—Palmieri's instrument, 2h. 03m. 40sec. a.m., N. 4° 20′, N.W. 2° 50′, W. 3° 0′, S.W. 1° 0′.

A duplex pendulum in my drawing-room recorded 1 mm. of motion N.N.E.

46.—February 12th.—The first movements of this earthquake were felt as gentle tremors lasting at least 10 seconds. During this time a lamp about 5 feet long hanging from the ceiling was distinctly seen to be vibrating vertically. After this there came a series of strong horizontal motions. About half an hour before this disturbance, decided changes in level were observed in the level recorders. I recorded the shock at 2h. 56m. 20sec. p.m. Palmieri's instrument, a mile distant, gave a record at 2h. 56m. 58sec. p.m. In Yokohama Mr. Talbot recorded at 2h. 55m. 30sec. p.m. Palmieri's instrument gave records N.S. 7° 20′, N.W. S.E. 8° 20′, E.W. 10°.

Distribution like map 44. Simultaneously shocks were felt in the N.E. Peninsula of Awomori Ken, in the Kii Peninsula, Amakusa, and on the opposite coast of Eastern Shikoku.

	A.	F.	B.	E.	G.
Number of waves in 10 sec.	30	34	28	14	72 (ripples).
Period T	.39	.42	.39	.72	.39 } greatest pos-
Maximum amplitude a	1.2	.7	.8	2.2	.5 } sible values.
Maximum velocity V	19	10.1	13	19	12
Intensity $\frac{V^2}{a}$	300	145	210	170	128

For stations A, F, B, and E, corresponding waves have been taken. These waves have not in all cases been the largest. For instance, there is a wave in E, with a range of 5.5 mm., or 2.7 mm. amplitude.

In the house resting on shot or G there are only two noticeable waves, respectively of about .5 and .4 mm. amplitude. In all other diagrams there are many waves of this amplitude.

If we take 6 successive prominent waves in the E.W. diagram at A, we find by measurement from the diagrams that the average value for a is .4 mm., and the average period .3sec. This gives a maximum velocity of 8.3 mm. per second. This is the velocity which determines the projection of objects.

By a similar calculation for the same waves at E, we find that $a = 1.2$ mm. and $T = .66$sec. This gives a maximum velocity for projection of 11.4 mm.

For the house on shot the maximum velocity is 4.5 mm. From this we see that the *average* maximum velocity of motion sustained by the house is very much less than that experienced at the stations.

The *average* intensity $\frac{V^2}{a}$ at A, E, and G, calculated from the same 6 waves, is respectively 172, 108, and 108 mm. per sec.

If, however, we take the maximum intensity as exhibited at all the stations and the house, they are as seen from the table 300, 145, 210, 170, and 128 millimeters per second,—the last value being that for the house.

From these calculations it would therefore appear that the velocities causing projection, or the accelerations causing overturning, are greater outside the house than they are inside. It may therefore be safely stated that the foundations of this particular house exercise considerable influence in preventing the acquisition of earthquake motion.

The advantage gained by using shot foundations is however seen better by an inspection of the diagrams than from the calculations. From the diagram taken in the house, with the exception of two waves which are marked A and B, the motion has been practically nothing, whilst waves equivalent to A and B repeatedly recur in all the other diagrams. If we were to sum up the motion represented by all the waves recorded in the house and compare it with the motion represented by all the waves recorded at each of the other stations, the result would certainly show that the motion outside the house was very much greater than that which experienced inside the house.

At all stations the violent movements commenced suddenly, after about 10 seconds of tremors. These tremors were in every probability the vertical motion already mentioned.

At A the motion is equally N.S. and E.W.; the chief wave is however nearly from W. to E. At F the motion is for one or two waves equally N.S. and E.W., but after that the movement is principally N.S., that is to say, parallel to the foot of the slope at the bottom of which station F is situated. Possibly the E.W. component of motion was eliminated by the free surface of the slope to which it advanced at right angles. Compounding the first prominent motion of 1.5m. E. with .9m. S., we obtain a true motion of nearly 1.7mm. S. 63°. E.

At B the motion is equally E.W. and N.S. Compounding the first principal movement of 1.7m. E. and .9m. S., we obtain a true motion of 1.9m. S. 60 E.

At E the motion is chiefly E.W. Combining the first chief movement of 1.5m. E. with .5 S., we obtain a true motion of 1.6 S. 70 E.

It will be observed that these last three directions for the first shock are practically identical.

Velocity.—If the motion reached station F at 0, then it reached B at .039, or .06 later, and E. at .164 or .152 later than at E.

47.—February 27th.—This disturbance was so slight that I did not feel it whilst seated in the college.

Palmieri's instrument, 1h. 37m. 29sec. p.m., N. 1°.30′, N.W. 2° 20′, W. 2°.0′. Distribution like map 102, being strong to the North of Tōkiō.

	A.	B.	E.	House.
Number of waves in 10 sec.	32	32	36	—
Period T.	.24	.28	.25	—
Maximum amplitude a	.1	.12	.05	.04
Maximum velocity V..............	2.6	2.7	1.2	—
Intensity $\frac{V^2}{a}$	67	60	28	—

At A the motion is chiefly W.E., at B it is chiefly N.S., whilst at E it is equally N.S. and W.E.

A duplex pendulum in my drawing-room indicated .3 mm. N.S.

48.—February 28th.—This earthquake was very slight. Palmieri's instrument, 10h. 20m. 05sec. p.m., N. 2° 50′. Distribution over a small area to west of Tōkiō towards Hachioji.

Simultaneously a shock was felt across the middle of the Kii peninsula and the eastern end of Shikoku.

	E.
Number of waves in 10 sec.	50
Period T.	.18
Maximum amplitude	.05
Maximum velocity V.	2
Intensity $\frac{V^2}{a}$	80

The remarkable point to be observed is the shortness of the period at the station E upon the marsh. The record obtained in the house on shot has about the same amplitude as that at E. Its period is, however, much greater, averaging .3 sec.

49.—March 12th.—At the time of this earthquake I was sitting alone upstairs. I felt very gentle tremors and saw a lamp vibrating very quickly up and down. This lasted 10 or 15 seconds, after which came a decided shake, and other people in the house first recognized that there was an earthquake. In my drawing-room a duplex pendulum gave a record of .4 mm. about N. and S.

In Yokohama the time was 4h. 22m. 44sec. The shock was sharp but without peculiarities. Felt over a small area parallel to the north side of the Tonegawa near stations 10 and 12.

The directions and intensities were :—

	A.	B.	E.	G.
Number of waves in 10 sec.	30	26	18	48
Period T	.18	.29	.64	.31
Maximum amplitude a	.1	.3	.6	.1
Maximum velocity V	3.4	6	5.8	2
Intensity $\frac{V^2}{a}$	115	120	56	40

The small amount of motion experienced by the house on shot at G is better seen by reference to the diagram, which is little more than a series of small ripples.

50.—March 20th.—Whilst taking lunch at the club in Yokohama at 12h. 58m. 35sec. I felt the earthquake as an easy gentle swinging movement. In Tōkiō it was felt severely.

Distribution very similar to map 44, extending to the west to Kofu.

	A.	J.	B.	E.	H.
Number of waves in 10 sec....	30	26	30	14	12
Period T..........................	.44	.55	.53	1.4	.85
Maximum amplitude a.	1.3	1.2	1.4	1.9	.35
Maximum Velocity V.........	18	13	16	8	.25
Intensity $\frac{V^2}{a}$	249	140	182	34	1.7

From the above table it is evident that the projecting effort V at any of the stations was very much greater than it was in the pit H. The same may be said with regard to the overturning efforts.

If we simply compare the motion experienced in the pit with that experienced immediately above it, at the station J, not 20 feet distant, the range of motion ($2a$) in the pit was to that on the surface as 1:43. The maximum velocity at these places being as 1:52, and the maximum accelerations being as 1:82.

The vertical motion recorded at J had a period or an average period of .37sec. with a maximum amplitude of .1mm.

Direction.—At A the preliminary tremors extend over about 5 seconds, after which the motion appears to be equally E.W. and N.S. The first motion was .8 S. and 1.1 W., indicating a true motion of 1.5 W. 40° S. The second lurch was 2.5 S. and 1.5 W., indicating a true motion of 3 W. 60° S.

At J the preliminary tremors continue over a rather longer period than that indicated at A. The first wave was 1.2 S. and .4 E., indicating a true motion of 1.2 S. 20° E. The second wave is 2.3 S. and .5 W., indicating a true motion of 2.3 W. 80° S. The motion is more pronounced on the N.S. component.

At B the preliminary tremors are also recorded as the commencement of the motion, but as the record was lost by the accidental breaking of the original plate it is impossible to compare similar waves. The motion is rather more pronounced in the N.S. component than in the E.W. component.

At E the motion at first is chiefly E.W. Subsequently it is principally N.S.

Velocity.—The intervals in the times of arrival of similar waves at A, J, and B, were as follows :—

	WAVE *a*.	WAVE *b*.
At A	1.99 sec. ...	4.11 sec.
At J	3.03 sec. ...	5.26 sec.
At B	3.11 sec. ...	—

Therefore the wave *a* arrived 1.04 sec. at A before J, while *b* arrived 1.15 sec., and the wave *a* arrived at A 1.12 sec. before reaching B.

From the above it would appear that different waves travel with different velocities. This is also indicated by the variation in the period of a given wave as recorded at two stations. For example at A the period of *b* is .44 sec., whilst at J, on harder ground, it becomes .42.

III.—CONCLUSIONS.

1.—Number of Waves in Ten Seconds.

The following table gives the number of waves which have occurred in ten seconds at the different stations. The last line gives average values for these numbers :—

Table I.

Number of Waves in Ten-Seconds.

1884-1885.	A	B	C	D	E	F	G HO SE	H PIT	J	
March 25th	22	18	......	......	....	......	....	......	...	
March 31st	36	32	23	......	....	......	....	......	...	
April 6th	30	25	32	......	....	......	....	......	...	
May 6th	32	26	35	......	....	......	....	......	...	
May 11th	30	27	35	......	....	......	....	......	...	
May 19th	37	33	21	......	....	......	....	......	...	
May 19th	22	26	......	......	....	......	....	......	...	
May 30th	28	21	......	......	....	......	....	......	...	
May 31st	31	28	......	......	....	......	....	......	...	
June 11th............	32	26	......	26	....	......	....	......	...	
October 24th	36	30	......	......	....	......	....	......	...	
November 16th ...	34	32	......	38	....	......	....	......	...	
November 21st ...	36	35	......	38	....	......	....	......	...	
November 27th ...	36	28	......	38	....	......	....	......	...	
November 29th ...	26	18	......	......	....	......	....	......	...	At D too irregular to estimate.
December 7th......	......	34	......	......	....	......	....	......	...	At D too small to estimate.
December 9th......	24	......	......	24	....	......	....	......	...	
December 16th ...	30	28	......	40	....	......	....	......	...	
December 23rd ...	......	26	......	......	....	......	....	......	...	Round Tōkyō Bay, strong Kadzusa.
December 30th ...	32	......	......	42	30 or 16	......	....	......	...	
Jauuary 2nd	......	26	......	26	40 or 12	40	....	......	...	
February 1st	28	20	......	......	....	......	....	......	...	N.W. quake.
February 4th	30	30	......	......	24	......	....	......	...	
February 12th ...	30	28	......	......	14	34	72	......	...	Ripples.
February 27th ...	32	32	......	......	36	......	....	......	...	
February 28th ...	......	......	......	......	50	......	....	......	...	
March 12th.........	30	26	......	......	18	......	48	......	...	
March 20th	30	30	......	......	14	......	....	12	26	
Average	30	28	29	34	23 or 28	37	60	12	26	

An inspection of the above table shows that the largest number have been recorded in the house resting on shot. An inspection of the diagrams, however, shows that these waves are usually little more than small ripples of very small amplitude.

Although the shortness in period would tend to make the motion destructive, this is counterbalanced by the smallness of the range of motion. The fewest number of waves have been recorded in the pit.

Taking the ordinary stations on the surface of the ground, the greatest number have been recorded at D and F. Had more earthquakes been recorded at C, its average number would probably have been increased. Generally speaking the greatest number of waves occur in a given period wherever the amplitude is small. The fewest number of waves have been recorded at E, where the amplitude has been large, and, it may be added, the ground very soft.

In looking down the list it will be seen that the ratio between the number of waves recorded at any two stations has not been constant. Thus, the ratio between the waves recorded at A and B has once been as 36:32 and in another case as 36:18; a more striking result is the fact that the number of waves at any given station has not been constant. This is especially noticeable at stations situated on soft ground like B and E. The first conclusion to be derived from this would be that the vibrations have been more is less forced, and that such is more or less the case is testified by the notches and other irregularities often observable in a set of earthquake waves. This irregularity is, however, partly explicable from the fact that the vibrations resultant from a shock wholly confined to soft ground vary in period with the intensity of the initial disturbance and they die out as the disturbance radiates. It therefore might be argued that the long period disturbances at any given station represent the vibrations due to a disturbance the origin of which is remote, or that they are due to a disturbance of feeble intensity the origin of which might be comparatively near. These assumptions, however, would not explain the irregularites in the waves.

2.—Period of Largest Waves in Seconds.

The following table gives in a collected form the periods of the largest waves observed at the different stations in different earthquakes:—

Table II.

Period of largest Waves in Seconds.

1884-1885.	A	B	C	D	E	F	G HOUSE	H PIT	J
March 25th	.73	.85	....	....	....	....	....	....	....
March 31st	.30	.24	.33	....	....	....	....	....	....
April 6th	.36	.61	.36	....	....	....	....	....	....
May 6th	.47	.70	.36	....	....	....	....	....	....
May 11th	.35	.47	.26	....	....	....	....	....	....
May 19th	.23	.36	.20	....	....	....	....	....	....
May 19th	.40	.50	....	....	....	....	....	....	....
May 30th	.36	.40	....	....	....	....	....	....	....
May 31st	.35	.30	....	....	....	....	....	....	....
June 11th	.36	.36	....	.36	....	....	....	....	....
October 24th	.32	.41	....	....	....	....	....	....	....
November 16th	.47	.47	....	.23	....	....	....	....	....
November 21st	.27	.45	....	.30	....	....	....	....	....
November 27th	.45	.36	....	.20	....	....	....	....	....
November 29th	.36	.56	....	.40	....	....	....	....	....
December 7th	....	.24	....	.24	....	....	....	....	....
December 9th	.40	....	....	.40	....	....	....	....	....
December 16th	.45	.54	....	.37	....	....	....	....	....
December 23rd	....	.40	....	....	....	....	....	....	....
December 30th	.32	....	....	.18	.75	....	....	....	....
January 2nd	....	.70	....	.18	.9	.18	....	....	....
February 1st	.45	.82	....	....	.5	....	.18	....	....
February 4th	.21	.30	....	....	....	....	....	....	....
February 12th	.39	.39	....	....	.72	.42	.39	....	....
February 27th	.24	.28	....	....	.25	....	....	....	....
February 28th	....	....	....	....	.18	....	....	....	....
March 12th	.18	.29	....	....	.64	....	.31	....	....
March 20th	.44	.53	....	....	1.4	....	....	.85	.55
Average	.29	.46	.30	.28	.66	.30	.44	.85	.55

As the previous table gives numbers which are directly proportional to the average period observed at different stations, the results to be deduced from the above table are, as might be anticipated, little more than repetitions of the conclusions already arrived at. First it will be observed that the period at any given station has not been constant. Second, that the ratio of the period at any two stations has not been constant, and thirdly, that the longest period has been observed at stations like E and B situated on soft ground or in the house at G.

Whilst the shortest period has been at stations like C and D, situated on comparatively hard ground.

3.—Maximum Amplitude in Millimeters.

The amplitudes recorded in the following table are measured on the same waves which were used in calculating the periods in the last table :—

Table III.

Maximum Amplitude in Millimeters.

1884-1885.	A	B	C	D	E	F	G HOUSE	H PIT	J
March 25th	.10	.5	...	...	...	...	...	...	...
March 31st	.1	.14	.05	...	...	...	...	...	...
April 6th	.3	.8	.1	...	...	...	...	...	...
May 6th	.4	1	.1	...	...	...	...	...	...
May 11th	.3	.9	.1	...	...	...	...	...	...
May 19th	.07	.15	.04	...	...	...	...	...	...
May 19th	.1	.2	.02	...	...	...	...	...	...
May 30th	.05	.1	...	...	...	...	...	...	...
May 31st	.05	.1	...	...	...	...	...	...	...
June 11th	.15	.25	...	.1	...	...	...	...	...
October 24th	.07	.1	...	...	...	...	...	...	...
November 16th	.25	.3	...	.05	...	...	...	...	...
November 21th	.1	.25	...	.05	...	...	...	...	...
November 27th	.15	.25	...	.05	...	...	...	...	...
November 29th	.2	.6	...	.05	...	...	...	...	...
December 7th	.1	.2	...	.05	...	...	...	...	...
December 9th	.07	...	...	.05	...	...	...	...	...
December 16th	.8	1.2	...	.25	...	...	...	...	...
December 23rd	...	.1	...	...	...	...	...	...	...
December 30th	.45	...	...	.2	1.9	...	...	...	...
January 2nd	...	.25	...	.05	2.5	...	...	...	...
February 1st	.05	.07	...	...	.1	.05	...	...	...
February 4th	.05	.1	...	...	.05	.01	.05	...	...
February 12th	1.2	.8	...	...	2.2	.02	.5	...	...
February 27th	.1	.12	...	...	.05	.7	04.	...	...
February 28th	...	...	...	...	.05	...	...	...	...
March 12th	.1	.3	...	...	.6	...	.1	...	...
March 20th	1.3	1.4	...	...	1.9	...	...	.035	1.2
Average	.37	.40	.07	.09	.95	.19	.17	.035	1.2

The first point to be noticed in the above table is the great range of motion observed at any given station in different earthquakes. Although the greatest range of motion usually occurs upon the soft ground, this is not invariably the case. For very small earthquakes it would appear that sometimes the soft ground appeared to absorb the motion, and the record obtained would be less than upon neighbouring hard ground. In moderately strong earthquakes, however, the motion on the soft ground has been invariably very much greater than on the hard ground.

Comparing together the range of motion at any two stations, as far instance A and B, we see that although the motion has always been greater at B, yet the ratio of the amplitudes at these two stations has varied within considerable limits.

One explanation for these differences may possibly be due to the side from which the motion has approached these stations. The small amplitudes recorded at F are remarkable, inasmuch as this station is situated on soft ground. This station was, however, at the foot of a slope running N. and S., and in consequence it is possible that the E. and W. component may have been eliminated, whilst only the N. and S. motion parallel to the length of the bank was recorded.

4.—Relation of Amplitude and Period.

A striking feature in all earthquake diagrams which I have obtained is the variability in the period of the motion. The smaller the amplitude the shorter is the period.

Taking a number of successive waves in different diagrams, it appears that the period inceases very rapidly until the amplitude becomes large, after which the period ceases to increase or increases very slowly. The rate of this increase apparently depends upon the nature of the ground. Thus, at station B in the earthquake of March 25th, after the amplitude reaches 5 or 6 millimeters the increase in period is slight—up to this amplitude the increase in period is rapid.

These observations have considerable bearing on the maximum velocity and maximum acceleration as experienced in hard ground as compared with soft ground. The greater distructive effort in soft ground arises from the fact that the length of period is more than counterbalanced by the largeness of the amplitude.

5.—Maximum Velocity in Millimeters per Second.

The following table is calculated on the assumption of simple harmonic motion from the quantities given in the two preceding tables :—

Table IV.

Maximum Velocity in Millimeters per Second.

1884-1815.	A	B	C	D	E	F	G HOUSE	H PIT	J
March 25th	.9	3.7							
March 31st	2.1	3.6	.9						
April 6th	5	8	1.7						
May 6th	5.3	9	1.7						
May 11th	6	12	2.4						
May 19th	1.8	2.6	1.2						
May 19th	1.5	2.5							
May 30th	.9	1.5							
May 31st	.8	2							
June 11th	2.7	4.5		1.8					
October 24th	1.3	1.5							
November 16th	3.5	4		1.3					
November 21st	2.2	3.5		1					
November 27th	2	4.4		1.5					
November 29th	3.4	7		.78					
December 7th		5		1.2					
December 9th	1			.7					
December 16th	11	14		4.2					
December 23rd		1.5							
December 30th	9			7	16				
January 2nd		2.2		1.7	17	1.7			
February 1st	.7	.6			1.2				
February 4th	1.5	2							
February 12th	19	13			19	10.1	12		
February 27th	2.6	2.7			1.2				
February 28th					2		2		
March 12th	3.4	6			5.8				
March 20th	18	16			8			.25	13
Average	4.4	5.3	1.6	1.4	8.7	5.9	7	.25	13

An inspection of the above table shows that the greatest projecting power was experienced at E and the least at C and D, that is to say, the greatest destruction due to projection might be expected in the soft ground. The greatest maximum velocity recorded is only 19 millimeters per second.

6.—Maximum Acceleration in Millimeters per Second.

The figures given in the following table are calculated from the table of maximum velocities and the table of maximum amplitudes:—

TABLE V.

MAXIMUM ACCELERATION IN MILLIMETERS PER SECOND.—(INTENSITY.)

1884-1885.	A	B	C	D	E	F	G HOUSE	H PIT	J
March 25th	3	27	....	....	....	....	....	....	....
March 31st	44	92	16	....	....	....	....	....	....
April 6th	83	80	28	....	....	....	....	....	....
May 6th	70	81	28	....	....	....	....	....	....
May 11th	120	160	57	....	....	....	....	....	....
May 19th	46	45	38	....	....	....	....	....	....
May 19th	22	31	....	....	....	....	....	....	....
May 30th	16	22	....	....	....	....	....	....	....
May 31st	13	40	....	....	....	....	....	....	....
June 11th	48	81	....	32	....	....	....	....	....
October 24th	27	22	....	....	....	....	....	....	....
November 16th	49	53	....	34	....	....	....	....	....
November 21st	48	49	....	20	....	....	....	....	....
November 27th	27	77	....	45	....	....	....	....	....
November 29th	57	81	....	12	....	....	....	....	....
December 7th	....	125	....	28	....	....	....	....	....
December 9th	14	....	....	9	....	....	....	....	....
December 16th	151	171	....	70	....	....	....	....	....
December 23rd	....	22	....	....	....	....	....	....	....
December 30th	180	....	....	245?	135	....	....	....	....
January 2nd	....	19	....	58	116	58	....	....	....
February 1st	10	5	....	....	14	....	....	....	....
February 4th	45	40	....	....	....	....	....	....	....
February 12th	300	210	....	....	170	145	128	....	....
February 27th	67	60	....	....	28	....	....	....	....
February 28th	....	....	....	....	80	....	....	....	....
March 12th	115	120	....	....	56	....	40	....	....
March 20th	249	182	....	....	34	....	....	1.7	140
Average	75	75	33	55	79	101	84	1.7	140

Here, again, we see that the greatest acceleration which may be regarded as a fair measure of the shattering and overturning power of an earthquake, occurred on the softest ground, or at station E.

The greatest acceleration recorded was on February 12th, when at A it reached 300 millimeters, or about 1 foot per second.

When looking at the foregoing tables it must be noticed that the number of records at F, G, H, and J are too few to give average results. At F it will be observed that the records were usually as small as those obtained at C and D, although F was situated on soft ground. The only suggestion that I can offer to account for this is the fact that station F was situated at the foot of a slope, which cut off a greater portion of the motion advancing from the side of the higher ground at right angles to the direction of the length of the slope.

7.—House Resting on Shot.

As I have already stated, this experiment was very simila- to one carried out by Mr. David Stevenson in the arrangements he made for the lamp tables at several of the lighthouses on the coast of Japan. My experiments, when supporting the house in the way Mr. Stevenson supported his tables, although partially mitigating the suddenness of earthquake motion, were practically failures. The causes leading to failure were chiefly due to a surging movement produced at the time of an earthquake, the movements produced by persons moving about inside the building, and the movements produced by wind. Mr. Stevenson (*Nature*, August 6th, 1884) considers his tables successful. Where they were used, destruction has not occurred, but where they have not been used destruction has occurred. From all the facts that I can gather, Mr. Stevenson's tables appear to have been extremely unsuccessful; when they were used destruction has occurred, and where they were not used no destruction has taken place.

Brunton, in his paper on the Japan Lights (see Institute of Civil Engineers, No. 1,451, p. 9), tells us that shortly after erection, the free motion of the tables occasioned so much inconvenience that they had to be clamped, and for this reason Mr. Stevenson's arrangement was not adopted in lighthouses which were subsequently erected.

From enquiries at the Lighthouse Department, I find that Mr. Stevenson's arrangements were not in working order for at least 10 years, but, in 1882, wishing to give the tables another trial, several of them were put in working order. The result has been that on March 11th, 1882, at Tsurigisaki, where there was a table in working order, a number of the lamp-glasses on the burners were overthrown.

Sometime after a second shock produced a similar effect.

At neighbouring lighthouses, of which these are several (two being within 8 miles) not provided with aseismatic tables, no damage was sustained. The shock of March 11th was severe. It was felt for at least 300 miles along the coast. At Yokohama and Tōkyō, which are at no great distance from Tsurugisaki, the effects of the shock were carefully recorded. I am not aware that any small articles like lamp-glasses, bottles, and vases inside ordinary houses, were overthrown (see Trans. Seis. Soc. Vol. VII. Pt. 2 p. 41-44). The fact that no ill effects have been felt at other lighthouses provided with Mr. Stevenson's tables, like those in the Inland Sea and near Kiushiu, must not be regarded as an argument in favour of Mr. Stevenson's tables, insomuch as the earthquakes referred to were not felt in those districts.

As a further confirmation of the fact that an aseismatic joint made of balls, although theoretically of considerable value, is practically a failure, I may say that all persons who are acquainted with the lighthouse tables with whom I have spoken refer to them as failures. The only form of aseismatic joint which I have found successful has been one where something more like a layer of cast iron sand rather than a bed of balls has been used to break the continuity between a structure and its foundations. In consequence of experiments already detailed, I am led to the opinion that a light one-storied structure may with advantage be rested on layers of cast iron shot, especially perhaps on soft or marshy ground where a hard foundation cannot be obtained. The advantage to be gained is clearly shown in the account of the earthquake of February 12th, 1884. At some future time I hope to make experiments on a building resting on a layer of sand and gravel. Mr. James Bissett, of Yokohama, has suggested to me an actual foundation on sand or gravel. His suggestion is certainly deserving of attention.

8.—Observations in a Pit.

The observations which I have made in a pit led to results which were certainly unexpected. Until these experiments have been repeated and amplified the results they appear to indicate must be received with caution. First, it would appear that an earthquake's motion at a distance from its origin is practically superficial. Secondly it would seem that a building the foundalious of which rose freely from hard ground at the bottom of a deep trench ought to feel but little earthquake movement. Thirdly, taking the experiments made in the pit in conjunction with those made on the surface, it appears that although a station situated immediately behind a trench on the side opposite to that on which the movements advance may be in shadow, a station at some distance behind the trench may receive considerable movement.

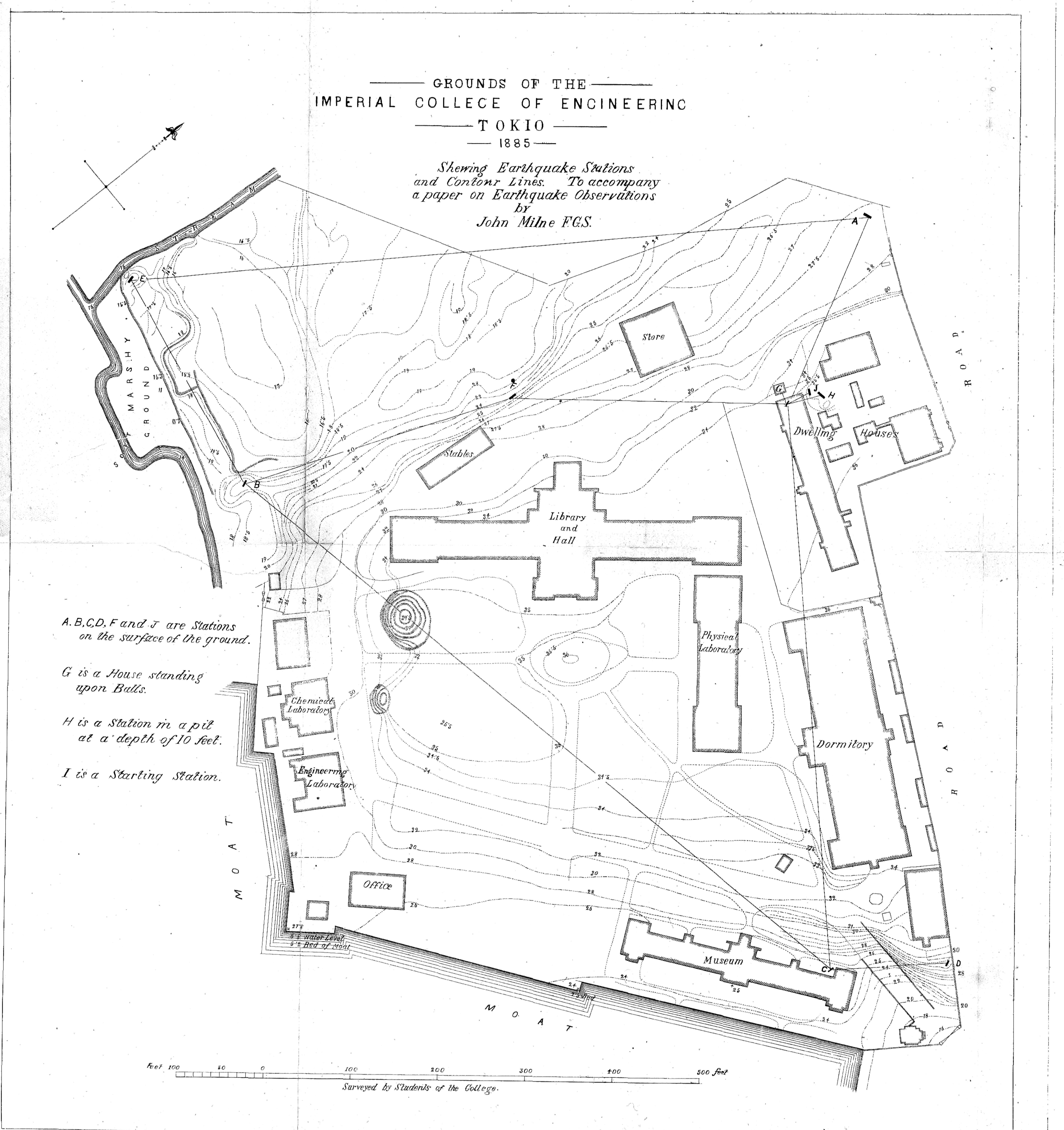
9.—Practical Conclusions.

The practical conclusions to be derived from what I have now given in detail are that there are at least three ways in which a considerable portion of the movement of an ordinary building may be avoided.

The first method of avoiding earthquake motion in a given district is to make a seismic survey of that area and then select the locality where the least motion is experienced.

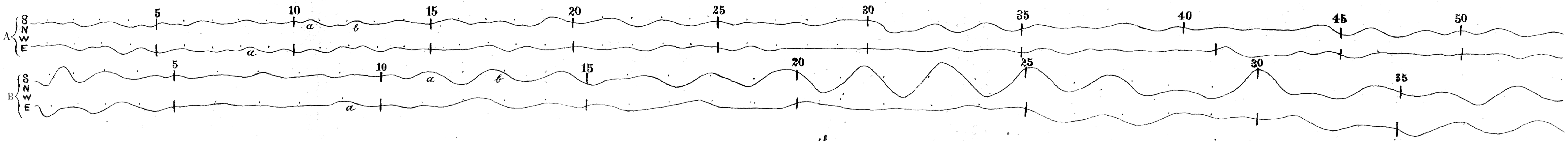
A second method by which motion may be cut off from a building is to rest it at each of its piers upon layers of cast iron shot.

A third method, which is applicable to heavy structures of stone or brick, is to allow them to rise freely from foundations on hard ground rising from a deep pit or series of trenches.

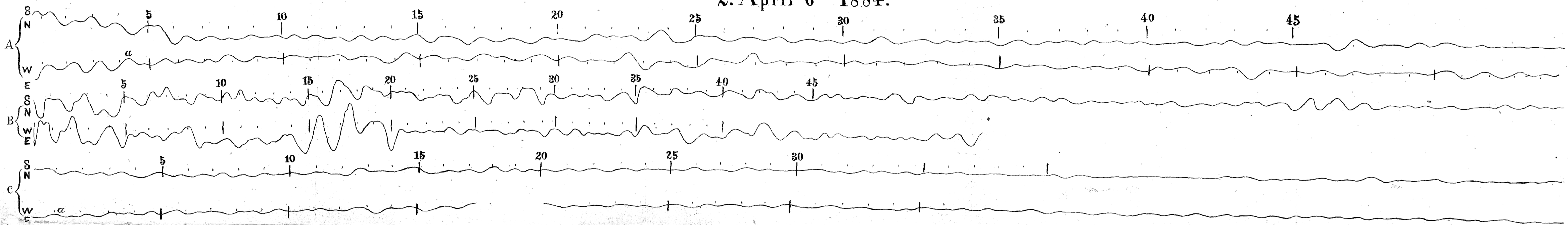

GROUNDS OF THE
IMPERIAL COLLEGE OF ENGINEERING
TOKIO
1885
Shewing Earthquake Stations and Contour Lines. To accompany a paper on Earthquake Observations by John Milne F.G.S.
A, B, C, D, F and J are Stations on the surface of the ground.
G is a House standing upon Balls.
H is a Station in a pit at a depth of 10 feet.
I is a Starting Station.
Store
Stables
Library and Hall
Physical Laboratory
Chemical Laboratory
Engineering Laboratory
Dormitory
Dwelling Houses
Office
Museum
MARSHY GROUND
ROAD
MOAT
Water Level
Bed of Moat
Mud
Feet 100 50 0 100 200 300 400 500 feet
Surveyed by Students of the College.

1. March 25th 1884.

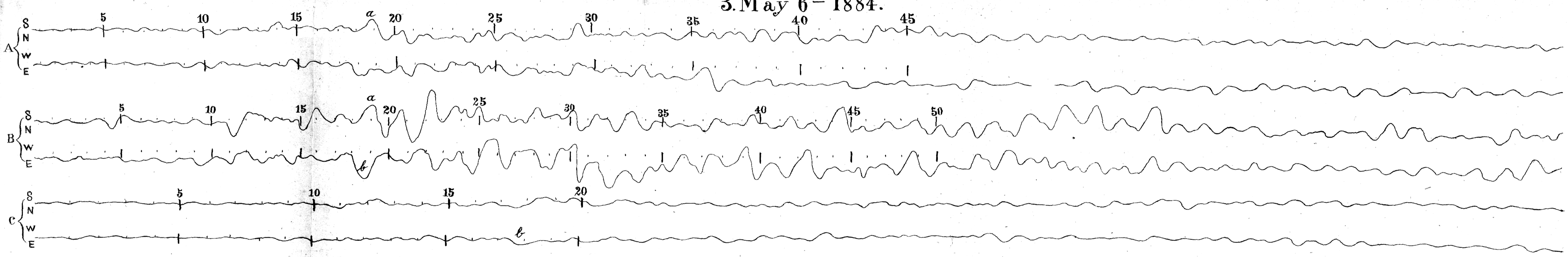
Time intervals = .366 Seconds.



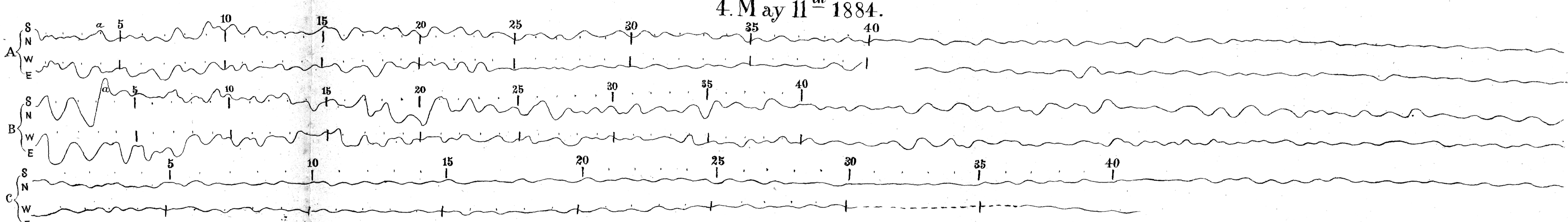
2. April 6th 1884.

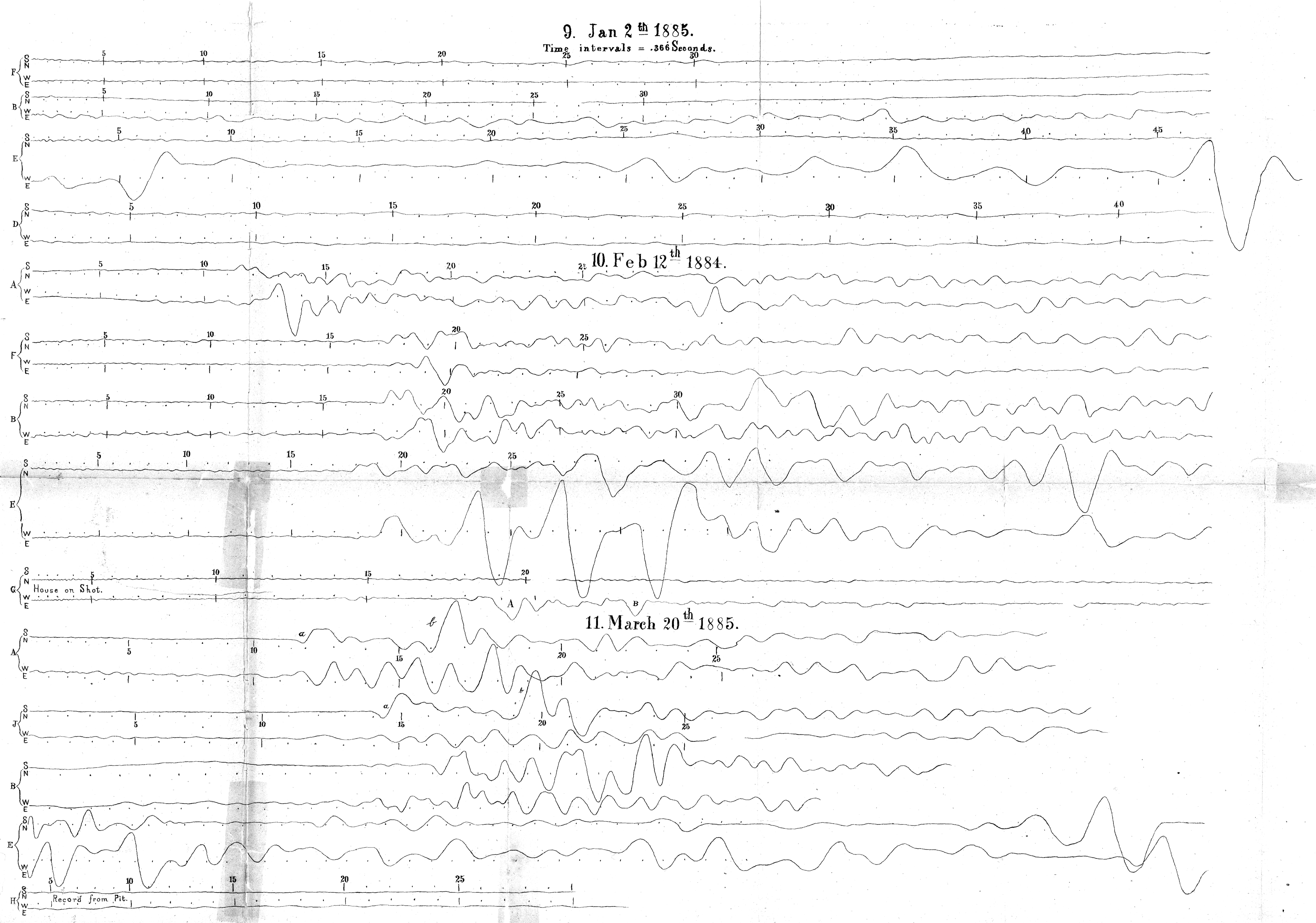


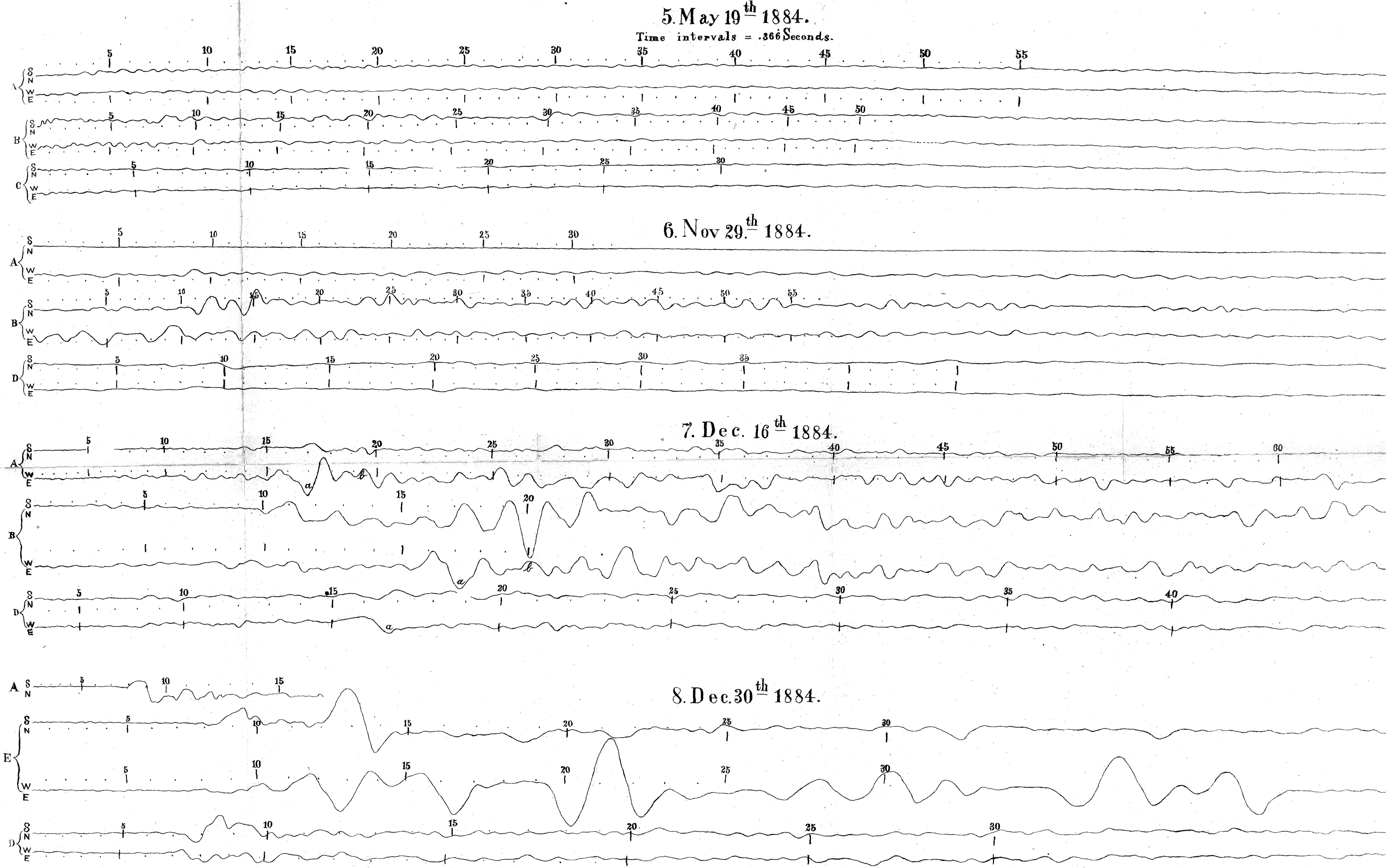
3. May 6th 1884.



4. May 11th 1884.




9. Jan 2th 1885.
Time intervals = .366 Seconds.
10. Feb 12th 1884.
House on Shot.
11. March 20th 1885.
Record from Pit.



5. May 19th 1884.
Time intervals = .366 Seconds.
6. Nov 29th 1884.
7. Dec. 16th 1884.
8. Dec. 30th 1884.