ON CONSTRUCTION IN EARTHQUAKE COUNTRIES.

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With an Abstract of the Discussion upon the Paper.

Reprinted from the Minutes of Proceedings of the Institution of Civil Engineers Vol. LXXXIII., Session 1885-6, Part I., Paper 2108.

Replies to the Discussion written in 1887, Tokio.

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 disturbance in a year. Some of these are simply tremors, whilst others have been sufficient to over-turn 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 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.[2] 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.[3]

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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.

[2] 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.

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

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.

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 only one earthquake out of many has 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.

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

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

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 dlfferent 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 maxium 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 Tokio 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 probable refers to the

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

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 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 saucerlike 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 ¼-inch cast-iron shot resting on flat plates. By this means friction has been so much increased that the house stands solidly, and unless its free foundations were pointed out, the peculiarities of the building would not be noticed. If moved by the application of levers, the building remains in the new position. Its behaviour at the time

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

of an earthquake may be judged by reference to the diagram of the earthquake of the 12th of February, 1884 (see Plate). With the exception of two waves marked A and B, the motion in the house 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 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 (see Plate), 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 earthquakes 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 brush-wood 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 building erected in an ordinary mannner, 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

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

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 Tôkiyô 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 horizotal 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. While speaking on this subject, a few words may be said about the 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

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

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 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-lines 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 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, 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.[2] 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 cause. The last chimneys inspected by the author were those of the British Legation, which

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[1] Vol, ii., pp. 32-48.

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

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 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 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 always 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 the accompanying Plate has been prepared.

APPENDIX.

OBSERVATIONS ON EARTHQUAKES AT TÔKYÔ.

I.—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					
Oct. 24	36	30							
Nov. 16	34	32	—	38					
Nov. 21	36	35	—	38					
Nov. 27	36	28	—	38					
Nov. 29	26	18	At D too irregular to estimate.						
Dec. 7	—	34	At D too small to estimate.						
Dec. 9	24	—	—	24					
Dec. 16	30	28	—	40					
Dec. 23	—	26							
Dec. 30	32	—	—	42	30 or 15				
Jan. 2	—	26	—	26	40 or 12	40			
Feb. 1	28	20							
Feb. 4	30	30	—	—	24				
Feb. 12	30	28	—	—	14	34	72	ripples	
Feb. 27	32	32	—	—	36				
Feb. 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 TÔKYÔ—*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 TÔKYÔ—*Continued.*

3.—PERIOD OF LARGEST WAVE IN SECONDS.

1884-1885.	A	B	C	D	E	F	G	H	I
March 25	0.72	0.85							
March 21	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					
Oct. 24	0.32	0.41	—	—					
Nov. 16	0.47	0.47	0.23	—					
Nov. 21	0.27	0.45	—	0.30					
Nov. 27	0.45	0.36	—	0.20					
Nov. 29	0.36	0.56	—	0.40					
Dec. 7	—	0.24	—	0.24					
Dec. 9	0.40	—	—	0.40					
Dec. 16	0.45	0.54	—	0.37					
Dec. 23	—	0.40	—	—					
Dec. 30	0.32	—	—	0.18	0.75				
Jan. 2	—	0.70	—	0.18	0.9	0.18			
Feb. 1	0.45	0.82	—	—	0.5	—	0.18		
Feb. 4	0.21	0.30	—	—	—	—	—		
Feb. 12	0.39	0.39	—	—	0.72	0.42	0.39		
Feb. 27	0.24	0.28	—	—	0.25	—	—		
Feb. 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 Tôkyô—*continued.*

4.—Makimum 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					
Oct. 24	1.3	1.5	—	—					
Nov. 16	3.5	4.0	—	1.3					
Nov. 21	2.2	3.5	—	1.0					
Nov. 27	0.2	4.4	—	1.5					
Nov. 29	3.4	7.0	—	0.78					
Dec. 7	—	5.0	—	1.2					
Dec. 9	0.1	—	—	0.7					
Dec. 16	0.11	1.4	—	4.2					
Dec. 23	—	1.5	—	—					
Dec. 30	0.9	—	—	7.0	1.6				
Jan. 2	—	2.2	—	1.7	1.7	1.7			
Feb. 1	0.7	0.6	—	—	1.2	—			
Feb. 4	1.5	2.0	—	—	—	—			
Feb. 12	1.9	1.3	—	—	1.9	10.1	12.0		
Feb. 27	2.6	2.7	—	—	1.2	—	—		
Feb. 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 TÔKYÔ—*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					
Oct. 24	27	22							
Nov. 16	49	53	—	34					
Nov. 21	48	49	—	20					
Nov. 27	27	77	—	45					
Nov. 29	57	81	—	12					
Dec. 7	—	125	—	28					
Dec. 9	14	—	—	9					
Dec. 16	151	171	—	70					
Dec. 23	—	22							
Dec. 30	180	—	—	245?	135				
Jan. 2	—	19	—	58	116	58			
Feb. 1	10	5	—	—	14				
Feb. 4	45	40							
Feb. 12	300	210	—	—	170	145	128		
Feb. 27	67	60	—	—	28				
Feb. 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

The replies to questions raised in the following discussion were intercalated by Mr. Milne in 1887, he not having been present when the paper was read. They do not therefore exist in the original paper. J. MILNE.

DISCUSSION.

Sir Frederick Bramwell, President, said that the author of the Paper was still resident in Japan. The Paper was one of an unusual character, which fortunately did not interest Englishmen very much. Some gentlemen might be present from Colchester who remembered the scare created not long ago by an earthquake in that neighbourhood. He hoped that any gentlemen having personal experience of earthquake countries might be able to give the Institution the benefit of their observations.

Professor John Perry observed that although he had had some acquaintance with the earthquakes of Japan, he had no personal knowledge of the actual measurements, such as those which Mr. Milne had been in the habit of making. In 1876 Professor Ayrton and he, living as they did in Japan, and having an experience of a considerable number of earthquake shocks, felt it to be their duty to pay a little attention at all events to the investigation of the subject. The results of their study were published in a few Papers shortly after that date. Those Papers brought out chiefly a principle, which, in their opinion, had been until that time completely neglected by persons making observarions on earthquakes in Japan and other countries; namely, that in considering the motion of a body when subjected to an earthquake, it was absolutely necessary to make into account the natural periodic time of vibration of that body; and they came to the conclusion that, in two widely different cases, the motion of a body relatively to the earth represented, with a very considerable amount of accuracy, the motion of the earth itself. In one case the body was a very quickly vibrating one, and its motions with regard to the box in which it was placed had to be very much magnified. In the other case the body was a very slowly vibrating one—slow compared with the motion of the earthquake, but its vibrations had to be damped by means of fluid friction. The second case was largely taken up and adopted in the making of seismographs, and all seismographs in use in Japan at the present time were based upon that second part of what they had called a "neglected" principle. They were bodies suspended in such a way that their natural periods of vibration were exceedingly slow. They still thought that the quickly vibrating body would give the best results, and they did not think that sufficient attention had been paid to the fact that the friction which stilled the vibrations of the recording body ought to be fluid friction. Having found a body which in its motion resembled the motion of the earth, they pointed out that it was necessary to register the motion of that body on three moving strips, one for the east and west motion, one for the north and south motion, and one for the up and down motion. In fact they pointed out how necessary it was to ascertain the actual motion of a point of the earth. Until that time observations had been made of the motions of such bodies as pendulums, hanging lamps, and hanging pictures—bodies which could get up a very considerable swing. The result was that sometimes a lamp, for example, would get up a great swing in a small earthquake, and sometimes after what was called a violent earthquake it did not seem to have any swing whatever. As another example, he might mention Mr. Mallet's seismometer, which consisted of a number of little vertical columns which rested on a level table. They were of different sizes, and of course the smaller column tumbled over with a small earthquake, and all the columns tumbled over with a big earthquake; and the direction in which they were found prostrate afterwards gave an indication of the direction of the earthquake. But it was found in Japan that the columns used to tumble in all directions; and on one occasion after Mr. Milne had, with the greatest possible patience, managed to balance a very small column, an earthquake which followed shortly afterwards upset every other column except this thin one. In the Papers to which he had referred they had calculated the periods of natural vibration of various structures, and had pointed out that if every part of the structure had a natural period of vibration very much quicker than the earthquake-vibration, there seemed to be no chance of its failure; but if a part of the structure had a period of vibration comparable with that of the earthquake, then differences in period of different parts of the structure might give rise to very great damage, unless there was a viscous resistance to motion which stilled the vibration. They pointed out that Japanese temples and houses which had very heavy roofs were not fastened to the ground, and were considered safe, and no doubt they were safe, but they rested on rounded detached stones, and if a slowly vibrating building of that kind were really well fastened to the ground the chances were, in fact it was almost certain, that it would be injured in the event of an ordinary Japanese earthquake. They also pointed out (in opposition to the practice of a considerable number of architects and engineers in Japan) that it was not right to have on a chimney a very heavy top, or to put a very heavy roof upon a building. They also demonstrated the danger of attaching chimneys to buildings, or attaching bodies together which had different rates of vibration. He mentioned those facts because the conclusions which they had drawn had been so thoroughly borne out by Mr. Milne's Paper. The obvious joke at the time was that the principle which they had called a neglected principle would remain neglected still. Indeed, when he considered the unscientific way in which observations on earthquakes were made at the time, and the exceedingly large amount of work involved in a scientific investigation of earthquakes such as they had proposed, his impression was that it would remain a neglected principle. But Mr. Milne's Paper had completely removed that impression from his mind.

When the Author began his work on earthquakes in Japan, Professor Perry feared that he was undertaking a hopeless task. The difficulties of meteorology were great; but they seemed to him small in comparison with the difficulties attending the pursuit of such observations as Mr. Milne proposed. He was warned that it was a rather thankless pursuit, but he refused to consider that suggestion. He used every instrument old or new that he could lay his hands upon and invented new instruments for himself. He buried microphones; he used long pendulums and Mallet's toppling columns. The slowly vibrating seismographs invented by Chaplin, Ewing, Gray, and himself, had, in his hands, for five or six years recorded every earthquake that had taken place at Tokio, at many stations both on the earth and under the earth. He had had, in fact, a monopoly of the subject, and appeared actually to love earthquakes while others feared them. It was difficult to express his admiration for the patience with which the Author had adhered to such laborious scientific work. He regarded the Paper as the best that had yet appeared on seismology. The fact that it was possible make a seismic survey; that in a mine or at the bottom of a 10-feet pit there was very little motion; that the nature of earthquake-motion was now known; that Stevenson's aseismic joint, after being discarded as useless, really possessed the elements of a very useful invention; and that it might now be hoped by experimental trench-digging or free foundations to ward off danger to a building; these appeared to him to be great additions by one worker to the knowledge of a very obscure subject in the course of six or seven years. Finally, Professor Perry referred to a pamphlet by himself and Professor W. E. Ayrton, "On Structures in an Earthquake Country," published in 1878.

Mr. R. Henry Brunton, as the Resident Engineer, entrusted with the construction of the Japanese Lighthouses mentioned in the Paper, congratulated the Author on being able to accomplish what he, during the ten years he was in Japan, had done his best to carry out. He had urged the Japanese Government officials to establish some system of observing earthquakes, but failed to obtain their sanction to move in the matter. In order to obtain the best possible information on the subject he put himself in communication with Professor Palmieri, of Naples, and the system he proposed to adopt was as follows: —At all the lighthouses round the coast records of meteorological observations were kept, which were sent to the lighthouse-office in the usual way, by the steamer calling once a month. By placing one or more seismographs at or in the vicinity of some of the lighthouse stations, records would also be obtained of the movements of the earth in different parts of the country. The adoption of this scheme, which had the approval of Professor Palmieri, afforded a means of judging of the positions of the centres from which the disturbances arose. The records obtained by Mr. Milne had been from observations made in such a narrow area that they were not of extended value. Assuming that an earthquake was brought about by some subterranean explosion, the disturbance caused by this was naturally transmitted to the surface of the earth, in its greatest intensity, in the line of least resistance, which was a line direct from the centre of the earth, called by Mr. Mallet, in his book on the Neapolitan earthquakes, the "Seismic vertical." From the seismic vertical the disturbance diminished in concentric waves on the surface. Of course the direction and force of those waves were altered by the different geological formations through which they passed. He always supposed that rock or compact soil would continue the motion well, while marsh land or clay, by its great elasticity, would tend to absorb it. If that theory of earthquakes was an accurate one, the importance of discovering the position of the centre of disturbance was plain, because not only would this enable an estimate to be made of the probable severity of a shock at any particular place, but also of the character of the shock—whether the motion was likely to be a horizontal or vertical one. It was clear that the nearer the seismic vertical the more the motion would partake of a vertical character, and the farther from the seismic vertical, the more likely there would be no vertical motion, but simply a horizontal one. The statement of the Author, therefore, that the vertical component in his observations was so small that it might be neglected, only tended to show that at Yedo or Tokio, where his observations were made, he was at a considerable distance from the centre of disturbance. The Japanese, of whom he had made inquiries, had told him, unanimously, that the most destructive earthquakes were always those in which there was a distinctly appreciable vertical motion. Their destructiveness was in great measure to be accounted for by the fact that the motion having been vertical, the localities were in close proximity to the centre of disturbance. During the discussion on his Paper on the Japanese Lighthouses, read before the Institution in 1876, Mr. Lloyd had given an instance of a globe on an ordinary table-lamp being pitched off by an earthquake without touching the chimney which protruded through it.[1] Likewise Mr. Brunton described how in a lighthouse at Sagami, situated about 20 miles from Yedo, the twenty-one Argand lamp chimneys were by an earthquake all pitched off their holders. The same earthquake turned round the upper six or seven courses of the chimney of the light-keeper's house, a column about 10 feet high, and 2 by 3 feet square, so that the upper part stood diagonally on the lower. These instances all give distinct evidence of a violent upward motion; they also pointed to the importance of a more extended system of observations. The Author had quoted a passage from Mr. Mallet's introduction to Palmieri's "Eruption of Vesuvius in 1872," in reference to the Japanese lighthouses. "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;" and he added, that this probably referred to the aseismic Tables which were devised by Messrs. Stevenson. To that Mr. Brunton emphatically demurred. Mr. Mallet had not, he

[1] Minutes of Proceedings Inst. C.E., vol. xlvii., p. 31.

believed, developed any system of aseismic joints, and there was no such joint in the constructive portion of any of the Japanese lighthouses. Mr. Mallet must have referred to the lighthouses as they existed. Two iron lighthouses were made in England, and sent out to Japan with those joints fitted to them, but they were (fortunately he thought) lost at sea. He said fortunately, because it gave him the opportunity of inquiring into the matter, and getting some personal experience of what an earthquake was. The decided conclusion to which he had arrived was that the tables of Messrs. Stevenson (from whom he was pained to differ) in their then existing state were impracticable and useless. Mr. Milne had stated the reason of their impracticability, which was their liability to be affected by ordinary disturbances, probably a great deal more than they would by moderate earthquakes. And the reason for their uselessness was, he believed, that every earthquake likely to be destructive to a well-built construction had a vertical motion. Those tables afforded no provision against this, but, by destroying the inertia of the structure, they would be probably mischievous in their effect. The decision at which he arrived in his designs for the Japanese lighthouses was to follow the principles enunciated by Mr. Mallet, and Professor Palmieri, to give the buildings weight and great inertia, coupled with a good bond between their various parts. Professor Palmieri stated that, although solidity and strength in a building did not afford perfect protection, still, so long as fracture did not occur, overthrow was impossible. That indicated the principle followed by him in the construction of Japanese light-houses. He thought that probably the improvement in the seismic joint made by Mr. Milne with shot, if he could get it sufficiently rigid as not to be moved by ordinary disturbances, might prove of some value in certain districts far removed from the centre of disturbance. In conclusion, he wished to express his sense of the extreme importance of such investigations to residents in earthquake countries, and to repeat that he was disappointed that the Author had not been enabled to carry his investigations over a wider field.

Reply.—Mr. Brunton regrets that the observations on which a great portion of the paper is founded had not been made upon a more extended area. In offering this remark, Mr. Brunton has apparently failed to recognize the main object of the investigations, which was to find out the differences in earthquake movement upon *extremely small areas.* The result of these investigations showed that the differences of intensity of movement even at places only a few hundred feet apart were extremely great. They are in fact so great that I am of opinion that on the area particularly referred to in this paper, two or more similar structures might be erected and by the same earthquake the one of them might be shattered and the other remain uninjured. I have every confidence in the accuracy of the experiments, as they were often repeated and the instruments interchanged. Details of the work in making this Seismic Survey are given in Trans. Seis. Soc. Vol. X., p. 1-36, where full sized diagrams of the records reproduced in this paper will be found.

Observations over an *extended* area are also made in Japan, distributed through which country there are about 650 observing stations, recording every year from 400 to 500 separate earthquakes. Accounts of this work, which amongst other things shows which parts of Japan are most shaken and which parts are hardly ever disturbed, can be found in Trans. Seis. Soc. Vol. VII., Pt. 2 and Vol. X.

Although the scientific results to be obtained from the general seismic survey of a country may be very great, from a practical point of view, as compared with the results to be obtained from a detailed seismic survey of limited areas in cities shaken by earthquakes they are relatively small. Seismic surveys such as referred to by this paper are easily undertaken, and the results they give show where we ought to build and where we ought not to build.

Although Mr. Brunton says soft marshy ground may tend to absorb earthquake motion, and although we are told that the temple of Diana was built on the edge of a marsh to preserve it from earthquakes, we must not conclude that marshy ground is the best place to build. Special experiments in this country have repeatedly shown that although the period of earthquake motion is increased on soft ground, the advantage thus gained, is more than counter balanced by the enormous increase in amplitude, and marshy ground is shewn to be one of the worst places on which to build. As one example of these experiments, see Trans. Seis. Soc. Vol. VIII. p. 1-82.

The example of destruction and disarrangement of lamps on aseismic tables at the lighthouses in Japan given by Mr. Brunton might be supplemented by several other examples (see reply to Mr. Stevenson's remarks.) I regret that I attributed the authorship of these tables to the late Mr. Mallet, but the reason for my error will be apparent to any one reading Mr. Mallet's introduction to Palmieri's Vesuvius. I cannot agree with Mr. Brunton's opinion that the twisting of chimneys at the time of an earthquake is an evidence of vertical motion. The only satisfactory explanation of this exceedingly common phenomenon with which I am acquainted, is the one first suggested by Mr. Thomas Gray (see Trans. Seis. Soc. Vol. I. Part II. p. 33).

Neither can I agree with Mr. Brunton, who, sharing the opinions of Mr. Mallet and Professor Palmieri, suggests that buildings to withstand earthquakes should have "weight and great inertia." If they have weight they certainly have "inertia," and it is the "inertia" of certain portions of a building which renders them self destructive. A building must have some inertia in its parts, but in my opinion this ought to be as small as is consistent with requisite strength, and the centres of inertia ought to be low.

Mr. W. W. Beaumont said he had not been in any country that deserved to be known as an earthquake country, but he had devoted a great deal of attention to the subject, having been engaged with the late Mr. Mallet in his investigations. Judging from the remarks of Professor Perry, he thought that he could not have read more than a fraction of the enormous quantity that Mr. Mallet had written on the subject of earthquakes.[1] Mr. Beaumont did not pretend to have read all that had been written by Mr. Mallet, but having been with him a good deal he had necessarily ascertained his views better than he could have done by reading. It appeared evident from the remarks of Professor Perry and Mr. Brunton, and from the Paper, that the origin of the Japanese earthquakes was, as a rule, at a very considerable distance from Japan. All the movements appeared to be horizontal, or so nearly horizontal that hardly any vertical component was observable. That was shown very plainly by the Author's observation as to the difference of movement at the bottom of the pit only 10 feet in depth. But it was not a new discovery. Mr. Mallet had observed that an earthquake was often cut off by a river, and a bank of a river had been seen in India on many occasions to lose a certain portion of its face, which was suddenly projected into the water. It had been found that an earthquake which had been noticed on one side of the river had not been observed on the other side, the energy of wave-transmission being dissipated by the projection of the material of the bank, and conveyed to the air and water. Such a wave of elastic compression could only be the expiring evidence of very distant impulse, and therefore of horizontal transmission. Another proof was that the direction of movement over even a very small area in Japan was very various, and any coseismal far from circular, showing that the impulse was probably distant, the direction of wave-emergence practically horizontal, and the velocity of wave-particle so small as to be affected by the heterogeneity of a very small depth below the surface. Professor Perry had referred to the columns used to indicate the direction and, to some extent, the intensity of the shock. Mr. Mallet only used that method where more delicate and better instruments were not obtainable. He had stated, in the directions pub-

[1] See especially Four Reports to the British Association for the Advancement of Science. First report, 1850, pp. 1–87. Second Report, 1851, pp. 272–320; Third Report, 1852, pp. 1–176; 1853, pp. 117–212; 1854, pp. 1–326. Fourth Report, 1858, pp. 1–136.

lished in "The Admiralty Manual of Scientific Enquiry," that these could be used when seismometers could not be obtained; but he would never have thought of employing them, nor of interpreting the indications of a few pillars, as giving information generally applicable from an area of observation so small as that described by the Author, and affording instrumental information of so complicated, confused, and so obviously local a character as that from this part of Japan. Mr. Brunton's remark as to the measurement of earthquakes appeared to indicate that he would like to undertake a survey even very much larger than that suggested by Professor Perry, and the end of which would be that if he obtained the information suggested, he would have to make every structure capable of withstanding the vertical movements and vibrations of steep emergence, as well as those movements which were worse than vertical, namely those observable at what Mr. Mallet had called the meizo-seismal circle, the co-seismal boundary of a seismic area, and one on which the amount of destruction was the greatest. That was to say, within this meizo-seismal zone the direction of shock would be more vertical, and the overturning power less, while outside it the direction would be more horizontal, but with velocity of wave-particle reduced by transmission. The aseismic joint was regarded by Mr. Mallet as merely a compromise. Even if it acted well, it would obviously only save from destruction just the upper part of a lighthouse tower, the lower part still having to sustain the shock. If it were strong enough it would move with the earthquake, or would resist the movement. Mr. Mallet held the view that three different systems of building were more or less suitable in any particular country. First, the structures should be so strong that their own inertia would not destroy them. Secondly, when it was impossible to construct buildings strong in that way, by binding them together thoroughly, or, if of other materials, by making them like a monolith, then he would build them of lighter materials—wood, or a light iron frame work—materials which had a greater amount of strength as compared with their inertia of rest or of motion. The third method would be one which would allow the structure to move a little. His idea was that a structure mounted on large shot would be likely to move so freely as to tend to its own damage or destruction, more especially in the secondary phase of the shock, and that the part so insulated would be pitched off or be more damaged than if it were ordinarily fixed. His view was that although not fixed, it should move only with difficulty. The Author remarked that Mr. Mallet had assumed that the action would always be of the nature of a sudden blow. It was difficult to understand how he could have come to that conclusion, for Mr. Mallet had taken the greatest trouble to show that the effect was not necessarily that of a blow, but might be one of extremely slow action. He had found that under favourable conditions, in an ordinarily heterogeneous rocky surface, as much as seven-eighths of the velocity of wave-translation was lost, and that the mischief was done by the often very low velocity of wave-particle. He had made experiments in Ireland over large areas and with heavy shots. In some cases he had produced imitations of earthquake waves, by large quantities of powder, and during the construction of the Holyhead Harbour he had measured the impulses obtained by the explosion of from 6,000 to 12,000 lbs. of powder at a time.[1] He had obtained results, which were in several respects similar to some of those indicated by the Japanese observations, as to the tremors which preceded and succeeded the main shock. They were referred to at length in the first, second, and fourth Reports to the British Association for the Advancement of Science. Briefly, in most cases there were secondary elastic waves accompanying the main earth wave. The subject appeared to resolve itself into what might be termed an intelligent comprehension of the effects of the inertia of the structures. The reference to the chimneys, to

[1] Report of the British Association for the Advancement of Science, 1861, p. 201; and Philosophical Transactions of the Royal Society of London, vol. 152, p. 663.

the twisting of buildings, to the effect of a band binding one portion of a structure to another, and so on, tended to show that any structure should be built with reference to the strength of the material as well as its mass. The buildings could be resolved chiefly into two classes: those that were made to cope with constant shocks of small intensity, such as occurred in Japan, and due generally to a distant impulse almost wholly horizontally transmitted; and structures made to cope with heavier shocks due to a less distant impluse, and not so small in vertical amplitude of wave-particle or so small in velocity.

It appeared from observations extending over a lengthened period, apart from the Author's experiments, that in Japan, as a rule, the shocks though constant were not frequently of very great intensity; so that he thought it would be wrong to arrive at any general seismological conclusions from the observations described by Mr. Milne. His Paper was of more interest to engineers than some Papers which had preceded it, because it dealt with the question as to what should be done to prevent the destructive action of earthquakes, instead of dealing with them from a purely seismic or geological point of view. He would remark that seismology, which owed its existence as a science to Mallet, did not depend for its completeness upon the minute accuracy of any one construction of seismograph or seismometer. Nothing had yet been done which added to the completeness of the discoveries and enunciations made by Mallet, and although more elaborate instruments might secure valuable observational statistics, they must always be interpreted by reference to the laws discovered by him, and to his work on the subject.

Reply.—Mr. Beaumont apparently considers that Japanese earthquakes spring from the centre at a considerable distance from Japan. Japanese earthquakes originate at many localities. The origins of nearly 1,000 Japanese earthquakes are indicated in Trans. Seis. Soc. Vol. VII., Pt. II. and Vol. X. Some of the origins are *very near* to Tokio and Yokohama. Others are near Hakodate, &c.

Mr. Beaumont does not regard the fact that in *certain* earthquakes there should be a difference between the movement on the surface and that recorded at the bottom of a pit only 10 feet in depth as a new discovery. To me the observation appeared novel. Not only Mr. Mallet, but nearly all seismologists have observed the effect of free surfaces like river banks and cliffs as places where earthquake motion was discharged, but I think my observation was the first which showed the effect of a *small* break in surface continuity and measured that effect. Whether the discovery was new or not, the observation is certainly one of great importance to all who have to deal with foundations. Mr. Beaumont declines to admit that Mr. Mallet assumed that earthquake motion acted as a sudden blow; but while discussing the matter, immediately speaks of the "velocity of wave translation" and "velocity of wave particle," as if they had an immediate connection with each other. As I read Mr. Mallet, it seems that all his calculations relating to overthrow or shattering are based on the assumption of a sudden blow (see Mallet's Neapolitan Earthquake Vol. I. p. 125, &c. Report to British Association 1858, p. 97, &c.) Mallet's velocities of earth particle for *projection* correspond to the maximum velocity of an earth particle calculated on the assumption of simple harmonic motion from the amplitude and period of a wave. The maximum velocities calculated by Mallet from the *overturning* of a body of given dimensions are quantities based on the assumption of a blow; conditions which do not appear to exist in earthquake motion. I may also add that these two quantities are employed by Mallet as if they were identical (see Neapolitan Earthquake Vol. II. p. 336, 349, &c.) My own investigations lead me to think that Mallet's second quantity is not admissable in Earthquake calculations. Bodies are overturned or shattered not by the maximum velocity an earth particle attains, but by the rapidity with which they receive motion or with which their motion checked. (See Trans. Seis. Soc. Vol. VIII. p.p. 35-73-81.)

As to Mr. Beaumont's statement that "nothing had yet been done which added to the completeness of the discoveries and enunciations made by Mallet," I will leave the answer to Prof. Forrel and others who joined Mr. Beaumont in the preceding discussion.

Mr. W. Galloway remarked that the first thing that had struck him in connection with the Paper, was the difference in the amplitude of the vibrations at the bottom and at the top of a pit 10 feet deep, a point that he regarded as new in connection with earthquakes. The general impression had been that a shock given to the crust of the earth would pass along the solid rock quite as well as along the surface deposits; and it had occurred to him that there must be something imperfect in the construction of the seismograph. Professor Perry had since described it, and it was obviously not so perfect as could be wished. He should like to see a series of results obtained simultaneously at different depths in a shaft at least 200 or 300 feet deep, before accepting such a conclusion as proved. The method of marking time and connecting the seismographs together, adopted by the Author, seemed perfect; the seismographs, on the other hand, were capable of much improvement. Some remarks had been made as to the observations proposed to be taken in the workings of collieries with the view of foretelling the occurrence of outbursts of fire-damp. The proposal was made in this country about six months ago, and a good deal was then said respecting it. A Paper on the subject had been read before the North of England Institute of Mining Engineers, by Mr. Walton Brown,[1] who suggested that if seismological observations were taken in mines, it might be possible to foretell outbursts of fire-damp, and thus prevent the occurrence of explosions. Mr. Galloway had written a short article on the subject in *Nature* in which he pointed out that those observations could not possibly be of use as a means of foretelling, because if cracks were formed by the disturbance it would be impossible to say where they were and how soon the workings of a mine would strike into them; they

[1] Transactions, vol. xxxiii., 1883-84, p. 179.

might be struck the day following the earthquake or not for years afterwards. He was, however, glad to observe from the Paper that the vibrations underground were so much smaller than on the surface; it prevented, he thought, a complication from being introduced into the question of explosions in mines.

Repty.—In answer to Mr. Galloway I fail to see that Mr. Perry has described the seismographs used in Japan. We have many seismographs all of which have yielded satisfactory results to the tests to which they have been subjected. Instruments of different construction when side by side give similar diagrams for the same earthquake. The same instruments placed on a "shaking table," the motion of which is recorded from outside, faithfully record this motion whether it is violent or gentle, slow or quick, long or short. Such test diagrams will appear in Vol. XII. of the transactions of the Seismological Society. If Mr. Galloway will suggest improvements on the instruments used in Japan he will be conferring a favour upon the workers in this country.

Mr. Galloway remarks that he would like to see the underground observation of earthquake extended before considering the present results as proved. So far as quantitatively proving the results I share Mr. Galloway's opinions, but that the effects underground are less than on the surface has already I think been sufficiently demonstrated. As to seismological observations being made in mines, I think there is some misunderstanding. Tromometrical observations might, I think, be made with advantage underground. Earth tremors are noticeable with steep barometric gradients and the escape of fire-damp follows barometrical depressions. If earth tremors precede barometrical depressions then tromometrical observations may be of great value to the coal mines. I commenced such observations at the Takashima coal mine in Japan several years ago. Subsequently similar observation were made in France.

Sir Robert Rawlinson, C.B., did not think that modern earthquakes could be clearly studied without some connection with geology, as there was no period in the history of the earth's crust, in which earthquakes had not occurred similar to those prevailing at the present time. Geology showed, on examining a good section of the earth's crust, that the prime dislocation and motion had necessarily been vertical, because mines were found displaced on the opposite sides of lines of faults; and on examining sand-stone rocks especially, it was found that the motion had been many times repeated, that the rocky sides had been rubbed together, until one had moulded itself into the other, and the substance of the rock had been altered and hardened in its character. When it was concluded that earthquake shocks were mainly horizontal, he ventured to say that every horizontal motion from an earthquake shock had proceeded from a vertical motion; in other words, that the line of axis which had caused the motion had been vertical, and that there had been a settlement of a portion of the earth's crust upon itself, causing reaction. It had been observed in California that the earthquakes in some regions had a reacting or dancing motion up and down for a considerable period of time. That was what must have taken place from remote periods, when the surfaces of the rocks along lines of faults had been rubbed together. The horizontal motion observed was an effect thrown out from the vertical motion, and carried on to the extent to which the shock was capable of being projected through the upper portion of the crust of the earth. The broad general fact had been laid down by Humboldt, that in all parts of the earth's crust liable to earthquake shocks there was, as shown by pendulum experiments, the thickest and densest crust—that there was over such areas a superincumbent mass of newer material laid upon the older rocks, such as the granites; and that in those places where the earth's crust had accumulated to a great extent of thickness, the extra weight of the earth tended to sink upon itself, or upon what had been termed "central heat," which, if by this was meant that the internal mass of the earth was semi-fluid through heat down to the centre, he did not believe. He thought that the earth's crust might be compared to a shell which was solid to a certain extent, and that the inner portion, whatever might be the thickness of the shell, would be cool, not probably as the outer surface, but as solid; and that the line of central heat would be in the centre of that solid crust, produced by the cohesion of the material, the heat being caused by the pressure of gravity. He had never tested a bar of good iron to the breaking point, without finding that when it was examined between light and dark, heat was developed visibly to the eye, and always electrically. In the newer and denser portions of the earth, there was a wasting of the great mountains, and the detritus was carried down by the rain and rivers and spread out over the profound depths of the ocean, which would naturally be the thinnest crust for the time being. When that accumulation and added pressure had taken place to a sufficient extent earthquake shocks were set up, and there were vertical risings of the earth's crust; while in the older worn out portions which had become thinner and lighter there was diminished heat, which tended to subsidence. All the regions of active volcanoes had the densest crust. The loftiest mountain ranges were in the earth's history, the youngest, far younger than the mountains of Scotland. That however was an abstruse question, and he would say no more about it.[1] With reference to the structures to be erected in earthquake countries, the remarks of the Author were not only applicable to those countries, but also to our own. Sir R. Rawlinson had paid attention to the construction of tall chimneys, and he knew that some in England had been brought to ruin by loading them with great lumbering and projecting cornices. Many buildings in London would not be safe if an earthquake shock took place, loaded as they were with overhanging stone cornices that did not balance

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[1] This central heat theory was promulgated about 1842, in a Paper, published in Liverpool, explaining that pressure generated heat and reactions.

themselves upon the structures, but were tied by iron clamps behind. That form of building ought not to be permitted. He agreed with the Author that structures that had to rise in elevation should be lightened as they rose, having a good foundation deep in the ground.

Mr. W. H. Thelwall said that the earthquakes to which the Author had referred appeared to be of a rather mild character. The earthquake that occurred in the Island of Ischia in 1883 was of a most destructive character, and an enormous amount of damage was done in the island, two thousand persons having lost their lives and many more being injured. A Commission was sent into the island by the Italian Government to obtain information about the earthquake, aud to frame rules for the rebuilding of the structures. One town was so much injured that only one house out of more than six hundred was not damaged. It was suggested at the time that this was not an ordinary earthquake, but was the result of the falling in of subterranean caverns, but the Commission were convinced that this was not the case. The Commission first examined the island with the view of ascertaining the locality of the shock, and what portions of the island were comparatively free from danger, so as to recommend certain sites upon which buildings might in future be erected, and to condemn others as dangerous. It was ascertained that, speaking generally, buildings founded upon hard solid lava had withstood the shock successfully, while those founded upon looser or lighter materials, such as tufa or clay, had suffered very much. The effect of the shock was comparatively slight upon the sea-shore, but sites for building should have sufficient elevation (say from 30 to 50 feet above the sea), to be out of the reach of any violent waves caused by the earthquake, as such waves frequently caused more damage in washing away buildings than was occasioned by land shocks. When the shock occurred there was a very violent upward movement, not being confined, as in Japan, to a horizontal direction. In regard to the re-erection of buildings, it was pointed out that the first thing to do was to select eligible sites and to build wherever possible upon lava, and where that was not possible, to dig down to comparatively solid ground, and then fill in a heavy platform of masonry or concrete 3 or 4 feet thick, extending over the whole area of the building and projecting 3 or 4 feet beyond. The building of any kind of vaulting above ground was forbidden. Light arches were only to be allowed over windows and openings of the kind. The heavy flat roofs formerly used to a large extent were condemned. The Commission recommended that buildings should be chiefly constructed with an iron or wooden framework, carefully put together, joined by diagonal ties, horizontally and vertically, with spaces between the framework filled in with masonry of a light character. The joists and the roof-trusses were to be firmly connected together. In plan, buildings should be square, and when the direction of the last shock could be traced, one diagonal should be placed in this direction. Not more than two storeys above ground were to be allowed, and there might be one underground, but it must be of very moderate height. In no case was the height from the lowest point of the ground to the top of the walls to exceed 31 feet. Openings for doors and windows were to be vertically over each other, the jambs being not less then 5 feet from the corner of the building. No openings for flues were allowed in the thickness of the walls, and no projections from the face of the building, except light balconies of wood or iron. In solidly built structures, and particularly if there was only one storey above ground, the roofs might be covered with tiles, but these must be light and fastened with nails or hooks, so as not to be displaced even by violent shocks. In other cases zinc or corrugated iron was to be used, proper means being taken to keep out the heat. In certain buildings flat roofs would be allowed, but their construction must be of the lightest possible character.[1]

[1] The report of the Commission was published in full in the "Giornale del Genio Civile" for 1883. Fourth Series. Vol. iii., p. 541.

Reply.—The recommendation of the Commission appointed by the Italian Government to enquire into the destruction which occurred in 1883 at Ischia, that buildings ought to be placed on the solid lava or rise from solid ground is a confirmation of the results arrived at by the seismic survey referred to in this paper.

That flat roofs should be condemned is a conclusion which I am hardly inclined to endorse. A flat roof which is *light* and sufficiently tied to or extending over the supporting walls should in my opinion be extremely safe. A steeply pitched roof is certainly dangerous. Another regulation which I can not endorse is that windows and openings should be placed vertically above each other. To horizontally applied stresses such a line of openings is a line of weakness, and one along which fractures repeatedly occur.

Correspondence.

Mr. G. Bush considered it difficult to lay down any rule as to the motion of earthquakes. In the parts of South America when he had resided, the houses, and all large buildings such as warehouses, were erected of wood-framing and walled in and roofed with galvanized iron. One Government block of buildings in Iquique, built of stone and cement, had withstood very severe shocks, especially one in 1877, when it resisted the great wave. Earthquakes did not interfere much with modern structures, but there was great danger of fires, which had been caused in several instances by the upsetting of kerosene lamps. The current of shocks in Iquique was always north-east and south-west. At the silver mines the motion was scarcely felt, but the rumbling noise was very audible. On the Pampa of Tamburugal, which was 3,500 feet above the sea, internal rumblings were heard almost nightly, but surface motion was only occasionally experienced. The railway had not suffered from shocks, excepting in cuttings, where a few stones were occasionally discharged. Off the coast, on board steamers during an earthquake, the motion was distinctly felt. Since the Chilians had taken possession of Iquique, the Jefé Politico, Mr. Bulnes, had issued a decree that all roofs should in future be made of galvanized iron, to prevent sparks from setting fire to houses and other buildings; formerly they were constructed of wood and then covered with shells from the shore.

Professor C. Clericetti, of Milan, remarked that the Author was not aware of what the Italian Government had recently done in reference to earthquakes, and his statement on p. 15 should be modified. In July 1883 a terrible shock occurred in the island of Ischia, by which more than 2,300 persons lost their lives. Several descriptive memoirs had been written about it. The principal centre of destruction was Casamicciola, where the houses were entirely destroyed. On the 15th of September of the same year the Minister of Public Works appointed a Commission to consider the reconstruction of the public and private buildings which had been injured. The Commission was to indicate the most suitable positions in the island for building new thermal baths, and for the erection of a mortuary for the victims of the catastrophe. The report of the Commission was published in Rome at the end of 1883.[1] It treats at large of the different methods of construction proposed for localities threatened by earthquakes, and of those most suitable for the island of Ischia. Models of the different constructions in wood and combinations of wood and masonry which were adopted had been exhibited at the Exhibition.

Mr. Henry Dyer, Honorary Principal of the Imperal College of Engineering, Tôkiô, wished to bear testimony to the great industry and ability displayed by the Author in his investigations relating to Japanese earthqnakes, a work which had earned for him an honourable position alongside Mallet and Palmieri, the founders of the science of seismology. The purely scientific aspect of the subject had been fully discussed by the Author

[1] Relazione della Commissione per le prescrizioni edizilie dell' isola d'Ischia istituta dal Ministro dei Lavori Pubblici (Genala) dopo il terremoto del Luglio 1883. Inst. C.E. Tract, 4to, vol. 91.

in his reports to the British Association.[1] As he was either directly or indirectly interested in the chief buildings mentioned by the Author, he would briefly refer to the results of his experience in the design and the construction of buildings in Japan. He thought that the supposed necessity for making special designs for buildings in earthquake countries had a very bad effect on the development of architecture in those countries, as he was strongly of opinion that the main things to be attended to were good construction and a few elementary principles, which a short study of earthquake phenomena was sufficient to impress on any intelligent observer. From observation both in Japan and on the continent of Europe he could say that if more attention had been paid to construction and to those elementary principles, little or no damage would have been done by ordinary earthquakes. Against extraordinary shocks by which the earth was rent asunder it did not seem possible to take any precautions. Mallet held similar opinions, for in reference to the Neapolitan earthquake of 1857 he wrote :[2] "It was evident, that had the town generally been substantially and well built, or, rather, the materials scientifically put together, very few buildings would have been actually shaken down, even in those localities where the shocks were most violent, and their directions the most destructive. Thus the frightful loss of life and limb were as as much to be attributed to the ignorance and imperfection displayed in the domestic architecture of the people, as to the unhappy natural condition of their country as respects earthquakes;" and he gave many examples of buildings in which the masonry was of the best class, and such as would be so recognized in England, which stood uninjured in the midst of the ruins of those constructed of rubble stones with large ill-filled mortar joints. An ordinary Japanese house consisted of wooden uprights resting on rough round stones, and suppor-

[1] Repoıts of the British Association for the Advancement of Science, 1881, p. 200; 1882, p. 205; 1883, p. 211; 1884, p. 241.

[2] The "Great Neapolitan Earthquake of 1857," vol. i., p. 94.

ting a heavy roof. The uprights had few diagonal struts, and joints soon gave way, it was almost impossible to imagine a structure worse adapted for resisting earthquake shocks, as it was wanting in lateral stability, and the result was a total collapse with a comparatively slight shock. It ought to be observed that although the Japanese carpenters were very expert in the use of their tools, and the joints of their buildings were very neatly made, they had little or no idea of the proper disposition of material to ensure approximate uniformity of stress, and it was often found that the joints were snapped asunder on a sudden shock being giving to them. The fire-proof stores of the Japanese were made of a framework of wood covered with mud plaster to a thickness ranging from 1 foot to 2 feet, and had a roof of the same materials covered with tiles. Being at once stable and fireproof, they generally withstood the effects of both earthquakes and fires. These structures formed the patterns from which many of the buildings used by the foreign residents were designed, and here again was an example of the results of unthinking copying. The stores served their purposes well, but the so-called foreign houses, built with wooden frames and covered with thin layers of bricks, stones, or tiles, instead of mud, were deficient both in strength and stability. The wood, generally being green when first used, soon rotted, the joints of the covering gave way, and after a few years it was found cheaper to build new houses than to keep the old ones in repair. Add to this the fact that they were for the most part heated by stoves with badly fitted pipes, or with fireplaces with chimneys loosely built, and of the design mentioned by the Author, loaded at the top with a heavy head, which vibrated with a different period from the house, and so in consequence were generally cut across at the point where they passed through the roof on the occurrence of a slight earthquake, and it would be understood that earthquakes were not the only cause of the numerous nervous disorders so common among the foreign residents in Japan.

The main building of the Imperial College of Engineering at Tokio had been designed and built under the impression that fire was more to be dreaded in Japan than earthquakes, and therefore it was constructed almost entirely of brick, and very few special precautions had been taken against earthquakes. Some parts of the roofs were supported loosely on the walls, and at first the bricks were bonded with hoop-iron, but ultimately these precautions were abandoned, and great attention was paid to the construction, to ensure that the mortar and bricks were good, so that the walls might be as strong through the joints as through the bricks; and, as far as possible, a uniform distribution of weight was attempted, so that the different parts might vibrate with the same period. Where that was not possible it was so arranged that a difference in period could not do much harm. The height of the walls was moderate, and the towers were strengthened by tie-rods at the different stories. Chimneys were almost entirely avoided, the buildings boing heated by steam. The cracks mentioned by the Author were not caused by the earthquakes, but by the foundations not being sufficient, a result which was anticipated, and which arose from an undue wish to economise. No doubt after those cracks had been started the earthquakes caused them to lengthen, but not to any serious extent.

The workshops at Akabane, which were connected with the college, gave greater difficulty than the college buildings. That part of Tôkyô was an old sea bottom, and below the surface soil a layer of mud about 30 feet deep existed. Piles were driven into this and bound together, and on the top was placed a bed of concrete on which the workshops were built, so that they were really floated on the mud, and the result was perfectly satisfactory, no cracks of any importance appearing.

The stones most commonly used in the foreign buildings in Japan were not well suited to withstand the shocks of earthquakes, being for the most part volcanic mud stones. There was an abundant supply of granite and the harder volcanic rocks, but as a rule they were expensive on account of the difficulty of transportation. If these could not be used it would be better to build entirely of brick, for the soft stones weakened the buildings. The walls of the moats and castle gates in Japan, which had all the appearance of great stability, were almost always in a state of unstable equilibrium. The large stones were generally square or polygonal on their faces, but pyramidal in shape, coming very nearly to points at their backs, the spaces being filled up with loose rubble without cement of any kind. The bearing-surface at the faces of the stones being small a slight movement was sufficient to bring the whole construction down, a result which, however, was no measure of the intensity of the earthquake, as the building might have previously been on the point of slipping.

For dwelling-houses the modifications of external design required in Japan, as compared with Great Britain, arose not so much on account of the earthquakes as from the heat of summer, the colds of winter, and the typhoons of autumn. Iron roofs were good from a merely structural point of view, but in summer it would be almost impossible to live in the houses provided with them. If a non-heat-conducting material of the same strength and durability as iron could be found, it might be used. Similarly iron chimneys would be the causes of numerous fires, even when two tubes were placed concentrically with an air-space between them, for careless workmanship, bad material, and corrosion would soon render them dangerous. If the houses were so designed as to be comfortable as regarded temperature, and the construction made in good brick, or equally strong stone and morter, so that the walls were of nearly a uniform strength, if no unnecessary top weights were used, and if the various parts did not vibrate with different periods, they would withstand all ordinary earthquakes, and other precautions would be unnecessary, as these generally produced results more serious than those due to the earthquakes.

Reply.—Mr. Dyer's opinion that much of the destruction occasioned by earthquakes might be averted by attention to certain elementary principles is an opinion shared by many seismologists, and one object of the preceding paper has been to point out and emphasize certain of these principles. His opinion that Japanese structures are exceedingly ill adapted to resist earthquake motion is, however, one with which I can not coincide. In 1880 and 1887 it was shown in a most marked manner that ordinary Japanese buildings resisted earthquake motion much better than ordinary European built bungalows and framed structures with a stone or brick facing. The Japanese buildings which apparently suffer the most are the fire-proof stores which Mr. Dyer remarks generally withstand earthquakes. (See Trans. Seis. Soc. Vols. I., Part II., and Vols. XI.) The heavy roof on Japanese buildings is undoubtedly bad, but inasmuch as it is connected with the foundations by a complexity of jointed timbers, each joint having a certain amount of horizontal freedom, a movement at the base of the building is not necessarily communicated to the roof.

With a building framed on European principles there would be an effort to cause the roof to move with the remaining parts of the structure, resulting, especially where the roof is heavy in excessive strains and possible fracture. This multiplicity of joints in a Japanese building are well seen in the corbelling round the eves of temples, and it is the basket-like yielding of such joints as these which in great measure tends to save the building. Mr. Dyer states that the substantially built buildings of the Imperial College of Engineering have suffered but little. Cracks, however, have been formed; and at the time of earthquakes these have been observed to open or shut and occasionally to extended in length. Mr. Dyer's opinion is that the cracks which chiefly occur in the Dormitory and Museum (see plate) were not formed by earthquakes, but by bad foundations. If the foundations had been better, possibly the cracks might not have occurred, but that does not alter my own opinion, which is that they were caused by earthquake movements acting upon the weaker parts of the buildings.

My own house (see Dwelling House I. in plan) was on February 15th, 1887, certainly cracked from the top to the bottom by an earthquake and heavy stones forming the corners in some instances pushed a quarter of an inch. The building is of brick, with a stone foundation, stones at the angles, and an internal wooden frame.

At the workshops at Akabane, referred to by Mr. Dyer, one of the chimneys was cracked by an earthquake in 1880 and had to be strengthened by iron bands.

Mr. D. Earnshaw, during a residence of twenty-five years in Manila, had experienced hundreds of shocks of earthquakes, some of them very severe. The first was in June, 1863, which ruined more than half the buildings in the city, including the cathedral, where many lives lost, and the last in 1880, when three very severe shocks took place in two days, an unusual occurrence, as one heavy shock generally occured at intervals of about eight years. He had come to the conclusion that it was best to build as strongly as possible, and in the following manner: The building should be two-storied, and depend for its stability entirely on wood, and not on stone or brickwork, which should only be used for foundations and filling in sides or walls; wooden pillars about 12 inches square of sound well-seasoned timber should be set in concrete foundations abou. 6 feet deep, according to the soil, and carried up to the rooft These should be well strutted or tied with timbers 9 inches square, so as to form one frame set level with the stone floor below; timbers for carrying the upper floor-rafters should be well fastened through pillars with strong iron bolts and nuts; and the extremities of the timbers for carrying the roofing should be supported by three wooden or wrought-iron knees, with strong hardwood cotters through the projecting ends. In fact, the whole structure should be tied and bolted together as in building a ship. Many materials had been used for roofing, such as the heavy tiles made in the country and others imported there, when in 1880 fully 60 per cent. of the buildings in Manila having been ruined, an order was issued by the municipal authorities to use corrugated-iron or zinc-sheeting for that purpose. A diversity of opinion existed as to which was the best and most suitable, for not only had earthquakes to be guarded against, but an intense heat and disastrous typhoons. With regard to the latter, he had seen in 1881 sheets of iron flying about in the air like paper. On that occasion he had seen an iron roof carried though the air entire and landed on the top of a house some 200 feet distant. He therefore thought that a light, strong tile roofing was preferable to any other. It kept the houses much cooler than iron; it was not liable to be blown off, and it was much more durable than iron, and therefore cheaper in the end. The only objection to tiles was the extra weight, but if the ceiling under the roof was boarded, as it should be, with boards 1 inch thick, it would be strong enough to bear the weight of the roof should it fall in a severe earthquake. The house in which he lived covered an area of 5,000 square feet; it had a heavy tile roof which had withstood all typhoons and earthquakes, including the heavy one in 1863, and it was in thorough good condition. He considered arches over doorways useless, as they invariably gave way under a vertical movement, which as a rule caused much destruction; above doorways and openings timbers of sufficient strength should be inserted. Only in the bottom part of the building should stone or brickwork be used, and this should be tongued and grooved so as not to fall out of place, though any part might fall without materially affecting the strength of the building. The top storey and all partitions to rooms should be of boarding; other materials cracked or fell, and for a time rendered the house uninhabitable, besides damaging the furniture. Another most important thing to guard against in Manila was the "anay," or white ant, which should be done by carefully selecting the timber, as the majority of the buildings which fell in an earthquake were previously injured by white ants, causing them to give way with a moderate shake. Especial attention should also be paid to the quality of the lime and mortar used in construction. He could not agree with the Author as to the advisability of adopting loose foundations, as the impetus given to a structure by a heavy shock, would certainly cause the whole to move a great deal more than if the pillars were fixed in solid foundations, and firmly tied together. Neither did he think that one part was less liable to movement than another. The most solid ground should always be selected for building on, and close-proximity to the banks of rivers and canals should be avoided.

Professor F. A. Forel, not being an engineer, could not deal with the practical side of the question, but would confine himself to expressing his high sense of the value of the work carried out by the Seismological Society of Japan, and especially by the Author. The ardour with which scientists in that country had set to work to study seismic phenomena and the ingenuity they had displayed in devising instruments for recording them, were beyond praise. Professor Ewing's were the first seismographs to give an authentic diagram of earthquake shocks, and while in Europe investigators were embarrassed by delusions of long standing, it had remained for the younger science of the Far East to discover the true character of these great natural disturbances. More had been learnt from the seismograph-tracer of the Anglo-Japanese observers in two years, than twenty centuries of European science had been able to show. For his own part, he was happy to be able to confirm the discoveries of his colleagues of the East. The thousands of individual observations on earth-tremors in Switzerland which he had collected since 1879, had not been made with specially designed instruments, and they recorded only subjective impressions or the objective observations of witnesses often ill-prepared for the very delicate study of these phenomena. Nevertheless, they had indicated clearly the correctness of the interpretations of the Seismological Society of Japan.

The orogenic earthquakes of Switzerland were similar in their symptoms to the earthquarkes (of presumed volcanic origin) of Japan. He was also constrained to admit, from careful observation, that the shock was composed of a series of oscillations, relatively very slow, of small amplitude, following one another at a clearly defined interval; at first increasing intensity, and then decreasing. The horizontal movement was of much greater intensity than the vertical, but the direction of oscillation varied much from one locality to another; often from one district to another of the same town; at time even from one house to another. Sometimes it was the longitudinal component that dominated; sometimes to transverse. He could confirm, also, the great differenee in the sensitiveness of the soil to reaction under the influence of seismic disturbance. Certain parts of a town might suffer much more than others from same shock. Feeble shocks were never felt in particular quarters; in others they were always felt. The labours of his colleagues in Japan had thrown a new light on his observations. Thanks to their seismograph-diagrams, he was the better able to understand the effects shown at home. He was of opinion that the Japanese observations were applicable to the Swiss earthquakes, and he was glad to have the opportunity of testifying to the great merits of the work of the Seismological Society of Japan, and of its founder, Professor Milne.

Mr. E. G. Holtham remarked that the Paper furnished data for an estimate of the utility of observations entailing much labour and ingenuity. Most of the Author's conclusions were founded rather upon ordinary information and common sense, than upon disclosures afforded by his experiments or the records of instruments. The Tables given could not be said to establish more than the diversity that might characterise simultaneous indications, and the triviality of the circumstances to which this diversity was ascribable; and it followed that but little importance could be attached to such "seismic surveys" as the Author suggested. The line of averages at the foot of each

Table was no doubt intended to facilitate comprehension of this point, though it must be observed that the number of observations varied greatly in different columns. The diagrams, showing amplitudes of vibration at various recording stations, should have been accompanied by some kind of scale, though the information contained in the Tables apparently implied that the diagram-amplitudes were about five times as great as the earth-movement, the instruments being so constructed as to enlarge in recording, to some definite proportion that might as well have been given. The Author's conclusions were likely to be of use rather to the domestic builder or architect than to the engineer, who as a rule did not require to be cautioned against placing excessive weights at unnecessary heights. The vibrations set up by wind-pressures in the case of lofty structures were probably of more importance, and demanded more studied provisions than any recorded earth-tremors. Ordinary engineering structures such as girder-bridges, arches of moderate span, station-sheds, and roofs appeared proof against moderate shocks. None of the railway-works executed in Japan previously to 1882 had suffered from the effects of earthquakes, the greatest damage coming within his notice, as attributable to two rather severe shocks in 1880, being the starting of a few facing-stones attached to a timber-framed building of the kind generally considered in Japan to be earthquake-proof.

There was, however, an important class of structures upon which earthquake vibrations might have serious detrimental effect, namely, retaining walls. The Author rightly pointed out that any abrupt change of surface-conformation afforded scope to a free wave in place of a mere vibration. Nevertheless, even in this case the dimensions usually given would suffice to protect a wall against overthrow; but if the toe of the wall were not effectually secured against displacement, there might be a forward movement. In some of the old castles of Japan, very lofty scarp walls had withstood earthquake-vibrations satisfactorily. This was probably owing to the great batter or slope given to the lower part of such walls, which united in a curved sweep with the nearly vertical upper portion, making the whole approach the form of a comparatively small terrace-wall, erected upon the top of a heavily-weighted or pitched bank possessing great stability.

Reply.—The criticism that the Author offered upon Mr. Brunton's remark's in great measure apply to what Mr. Holtham has said. In Mr. Holtham's opinion but little importance can be attached to seismic surveys. Surely if Mr. Holtham had to build upon a plot of ground on one side of which the motion was found by a seismic survey to be often four or five times greater than it was on the other side, all other things being equal, he would not build upon the side of greatest movement? Another remark of Mr. Holtham is that much of what is said, is founded on "ordinary information and common sense." This I freely admit. "Ordinary information and common sense" are, however, often neglected. After the experiences of 1879 and 1880 many of the residents in Yokohama materially altered the form of their chimneys. In 1887 these buildings did not suffer. The buildings which did suffer being chiefly new buildings put up subsequently to 1880 and without any regard to the experiences of previous years. Mr. Holtham speaks of "the starting of a few facing stones attached to a timber-framed building of the kind generally considered in Japan to be earthquake proof." The building, or rather buildings referred to, are, I suppose, the two most important railway stations in Japan,—one at Yokohama and the other at Tokio. I particularly mention these buildings as Mr. Holtham was for some years connected with the Yokohama-Tokio Railway.

Had the builders of these stations been guided by the results of previous experience, inasmuch as it has often been observed that timber buildings faced with tiles or masonry are continually damaged by earthquake movement, it is my opinion that the damage referred to by Mr. Holtham would not have occurred. An interesting case of internal damage to a house is in the dwelling house erected under the supervision and from the designs of Mr. Holtham as his own residence. One of the chimneys in this building although clear of the floors, &c., through which it passes, has on several occasion illustrated the principle of non-synchronism in vibrational period. For some reason or other the vibrational period of the chimney and the building to which it belongs so far disagree in their movement, that the beading, plaster work, &c., which connect the two have on more than one occasion given way and fallen inward, naturally causing some destruction and no little alarm.

Mr. H. S. Ridings observed, from an experience of several years, when Resident Engineer of the Iquique Railway, Peru, that, as stated by the Author, the effect of earthquake vibrations varied much according to the nature of the ground. The confused direction of the motions was very apparent in structures embedded in sand, heavy bars of iron having been in May, 1877, twisted into an S-sharp. The subject of free foundations was of great importance. Instead of shot, a much simpler, cheaper, and more effective plan would be to interpolate a layer of clean coarse sand 1 inch thick, in a convenient position, care being taken to prevent it from escaping laterally, and from being washed out. The wall above this layer should be inset 2 inches or so on both sides. These remarks referred to concrete, brick, and stone structures. One of the largest buildings in Iquique had a heavy framework of timber, well braced, the interspaces being filled in with brickwork; this had resisted heavy shocks of earthquake.

Iron buildings and timber frame-houses, if carefully designed, and with an extra amount of diagonal bracing, seemed well suited for earthquake countries; but in the tropics they needed special provisions for ventilation. Such structures should not be bolted down to foundations of concrete or brickwork, except of course in the case of machinery, and one well-known engineer had found that it was better to embed iron columns in concrete rather than to hold them down with bolts.

The value of careful bracing had been well-shown in the case of a high timber staging and platform, carrying iron water-tanks, at Pozo d'Almonte, a station situated in the great plain of Tamarugal. Such a structure, from its top-heavy character, was particularly liable to failure during an earthquake. The earthquake of May, 1877, was at this place so violent that the ground was cracked, and the station-master, fearful of being engulphed, stretched himself at full length between the rails along the sleepers, thinking that the rails would form a sort of girder-bridge over any chasm which might open. Notwithstanding this excessive vibration the tanks remained in their places and the staging was uninjured. Again, he had seen a well-framed timber house of one of the Iquique merchants, the day after the earthquake, floating about in the bay, with a list caused by a heavy piece of furniture, but perfectly intact. This house not only resisted the earthquake vibrations, but the shocks of the great earthquake sea-wave.

It did not seem that the violence of the shock always diminished rapidly with the increase of depth below the surface. In many parts of Peru the ground for some feet below the surface was harder than farther down, which was probably due to excessive solar action for ages in a rainless district. In one case an English miner was employed to sink a shaft in a valley near La Noria. He pierced through the upper crust and got down to a depth of about 100 feet. One Saturday a payment on account was sent up to him from Iquique. This he placed in a box in the tent which he and two native helpers occupied, and then was let down by the natives by an ordinary jack roll and bucket. When down, the men pulled up the bucket, and decamped with the money. The miner tried to escape by cutting holes for his hands and feet, but a strong shock of earthquake occurred, and he fell from a height of about 15 feet to the bottom, from whence he was subsequently rescued.

As regarding vertical motion, the engineer's camp among the mountains must have been at one time pitched in the vicinity of an epicentrum. Once, on being aroused from sleep by an earthquake, he observed that the tent-pole was moving violently up and down. It should, however, be remarked that the relative heights of bench-marks did not appear to be altered by earthquakes. The City of Arequipa, Peru, was particularly liable to earthquakes owing to its proximity to the great volcano, the Misti, 19,000 feet in height above sea-level, the city being 7,000 feet above sea-level. The general construction of the houses is peculiar. A light-coloured volcanic stone was largely used; this when lately quarried, was easily shaped, and it hardened gradually. The roofs were for the most part strong arches, a very good mortar being used. In the earthquake of 1868, it was not so much these arches which failed as the walls, and the spandrels between the arches at front and rear. In some parts of the city arches extending in one direction stood, while those at right angles to these were thrown down. Since 1868 a good many corrugated-iron roofs had been introduced, but they were not well suited to the climate, and were not durable.

In conclusion, a short extract from Paper on the Iquique Railway, published in 1883, might be interesting.[1] The earthquake of the 9th of May, 1877, occurring as it did at night, and without warning, involved a direct outlay (for materials and wages) of $17,000 on the Iquique section, and a rather smaller, but still considerable expense on the Pisagua section; and the loss from suspension of traffic during repairs was of course much more serious. On that occasion the town line, used for taking the nitrate of soda to the various stores and wharves along the sea-shore, was destroyed, and in some places completely obliterated; the railway pier also was washed away, and the water condensers were much injured. Up the mountain the rails were in many places twisted in a most extraordinary manner; embankments were shaken down, leaving the rails suspended in the air, and rocks were thrown into the cuttings.

[1] Minutes of Proceedings Inst. C.E., vol. lxxii., p. 189.

Mr. D. A. Stevenson remarked that the Author appeared to claim as his own the principle of resting structures on balls, so as to break the continuity of the building with the foundation, with the view of mitigating the effect of earthquake shocks on the superincumbent structure. Mr. Stevenson and Professor Piazzi Smyth, the Astronomer Royal for Scotland, had had some correspondence on the subject with the Author,[1] in which they pointed out that Mr. David Stevenson had proposed this method in a Paper entitled, "Notice of Aseismatic arrangements, adapted to Structures in Countries subject to Earthquake Shocks;"[2] and further, that Messrs. Stevenson had designed and sent out to Japan, in 1869, several tables fitted with this contrivance for carrying the delicate optical apparatus in the lighthouses of that country.[3] He was pleased to find that the Author's experience proved the efficacy of Stevenson's method, more especially as he thought the lighthouse tables sent out to Japan had not had a proper trial. Thus Mr. Simpkin, who was employed in the lighthouse service in Japan, and who returned home in 1884, informed him that at Tsurugasaki and Kashimasaki lighthouses the aseismatic tables were firmly strutted with timber to prevent any motion, as inconvenience was felt from the oscillations of the table, when winding up the machine and cleaning the apparatus; the steadying screws sent out with the apparatus (made so that any degree of rigidity might be given to the table) having not been put in at these stations. These two were the only lighthouses at which any damage had been done by earthquake, while those stations at which the tables were in operation had never suffered at all, although they had been repeatedly subjected to shocks. Mr. Brunton had indeed expressed the opinion, and adopted as a principle, that "solidity, weight, and strength, as opposed to lightness and flexibility," was best, and he was by no means alone in this opinion as to

[1] "Nature," vol. xxxii., pp. 213 and 573; vol. xxxiii., p. 7.

[2] Transactions of the Royal Scottish Society of Arts, 1868, vol. vii., p. 557.

[3] Minutes of Proceedings Inst. C.E., vol. xlvii., p. 27.

the unsuitability of the aseismatic arrangement, for Mr. Robert Mallet, when consulted by Mr. Stevenson as to the exact phases of an earthquake shock, had written in 1868, acknowledging the receipt of a description of Mr. Stevenson's proposal, that if the balls and plates proposed were confined to the apparatus in the light-room, "he would augur much more favourably of the result being satisfactory"; but his own notion for Japan, or other shaky places, would be to make all the towers rather of timber or of boiler-plate. In the designs for the aseismatic joints for the lighthouse towers, which were lost at sea, the balls varied in number and size with the height of the towers.

Reply.—Mr. D. A. Stevenson is apparently under the impression that I claim the principle of resting a structure on balls. I do not claim this principle (see foot-note at the commencement of this paper. *The Times*, May 26th, 1885, &c.) As I have already explained, in consequence of certain ambiguity in the writings of Mr. Mallet which have been already referred to, I was at one time under the impression that Mr. Mallet was the author of the aseismic joint. One thing I may claim, is that after many experiments, a practical form of the joints has been discovered. This is a layer of cast iron shot, which Mr. Ridings and I myself have suggested (see *Nature*, Vol. 33, p. 439) might be replaced by a layer of clean coarse sand. Mr. Stevenson's method as applied to certain of the lighthouse tables in Japan, so far as observations have yet gone, has been unsatisfactory (see criticism on Mr. Brunton's remarks). Certainly the lamps upon such tables have often been deranged by earthquakes. The history of the working of these lamp tables is so far as I can learn as follows:—

1. Shortly after erection the free motion of the tables occasioned so much inconvenience that the European engineers then in Japanese service had them clamped, and the arrangement was not adopted in lighthouses subsequently erected (see Brunton on "The Japan Lights." Institute of Civil Engineers No. 1451, p. 9.)

2. I learn from the Lighthouse Department that in 1882, wishing to give Mr. Stevenson's tables another trial, several of them were put in working order. The result was that on March 11th, 1882, at Tsurugasaki, a number of the lamp glasses on the burners were overthrown. Sometime afterwards a second shock produced a similar effect. At neighbouring lighthouses, two of which are within 8 miles and not provided with aseismatic tables, no damage was sustained. The shock of March 11th was felt for at least 300 miles along the coast, and its eflects at Yokohama and Tokio which are at no great distance from Tsurugasaki were carefully recorded. I am not aware that any small articles like lamp glasses, bottles, vases, &c., in ordinary houses were overthrown. The fact that no ill effects occurred at other lighthouses provided with Mr. Stevensons tables like those in the Inland Sea and near Kiushu must not be regarded as an argument favourable to the tables, inasmuch as the earthquake referred to was not felt in those districts. It may here be remarked that one result of the general seismic survey of Japan shows that aseismic tables are no more required in certain portions of the empire than they are required in England.

As a farther illustration of the manner in which aseismatic tables have behaved, I quote the following translation of a report from the Chief Lightkeeper at Tsurugasaki :—

"Sir,—On October 15th, 1884 at 4.16 a.m., very severe shocks of earthquake were felt. The aseismatic table was in working order, but the shocks were so violent that fifteen lamp glasses out of the twenty-one in use were upset and broken. The lamps thus stripped of glasses began to smoke. The milled heads of the wick-holders being shaken off, and besides the revolving machine being in motion, we had some difficulty in replacing the glasses promptly; however, we managed to put them all in proper order again by 4.21 a.m.—I am, Sir, your obedient servant," &c., &c.

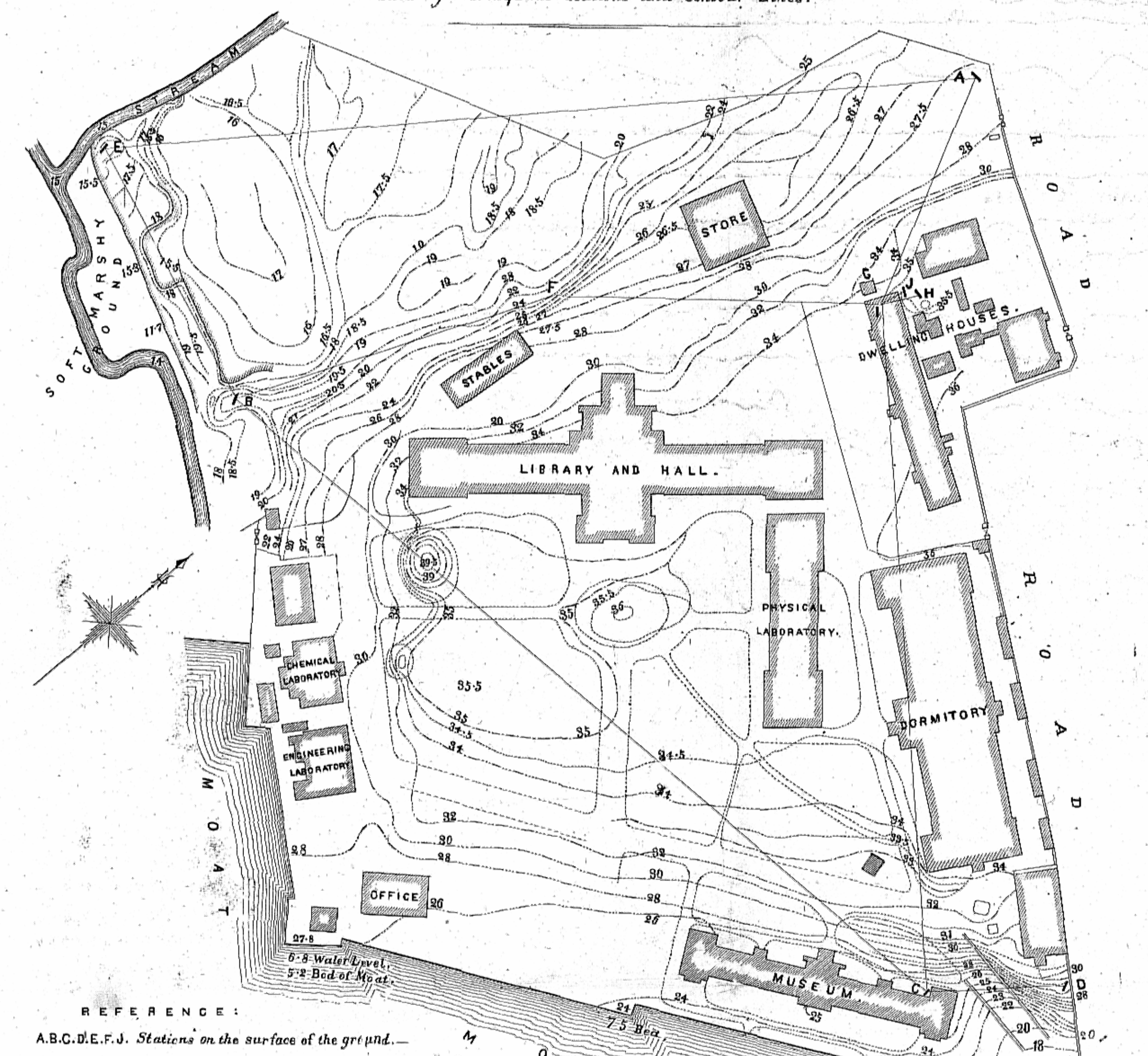
My own opinion is that Mr. Stevenson's aseismic tables are valueless.

CONSTRUCTION IN EARTHQUAKE COUNTRIES.

GROUNDS OF THE IMPERIAL COLLEGE OF ENGINEERING,

TOKIO, 1885.

Shewing Earthquake Stations and Contour Lines.

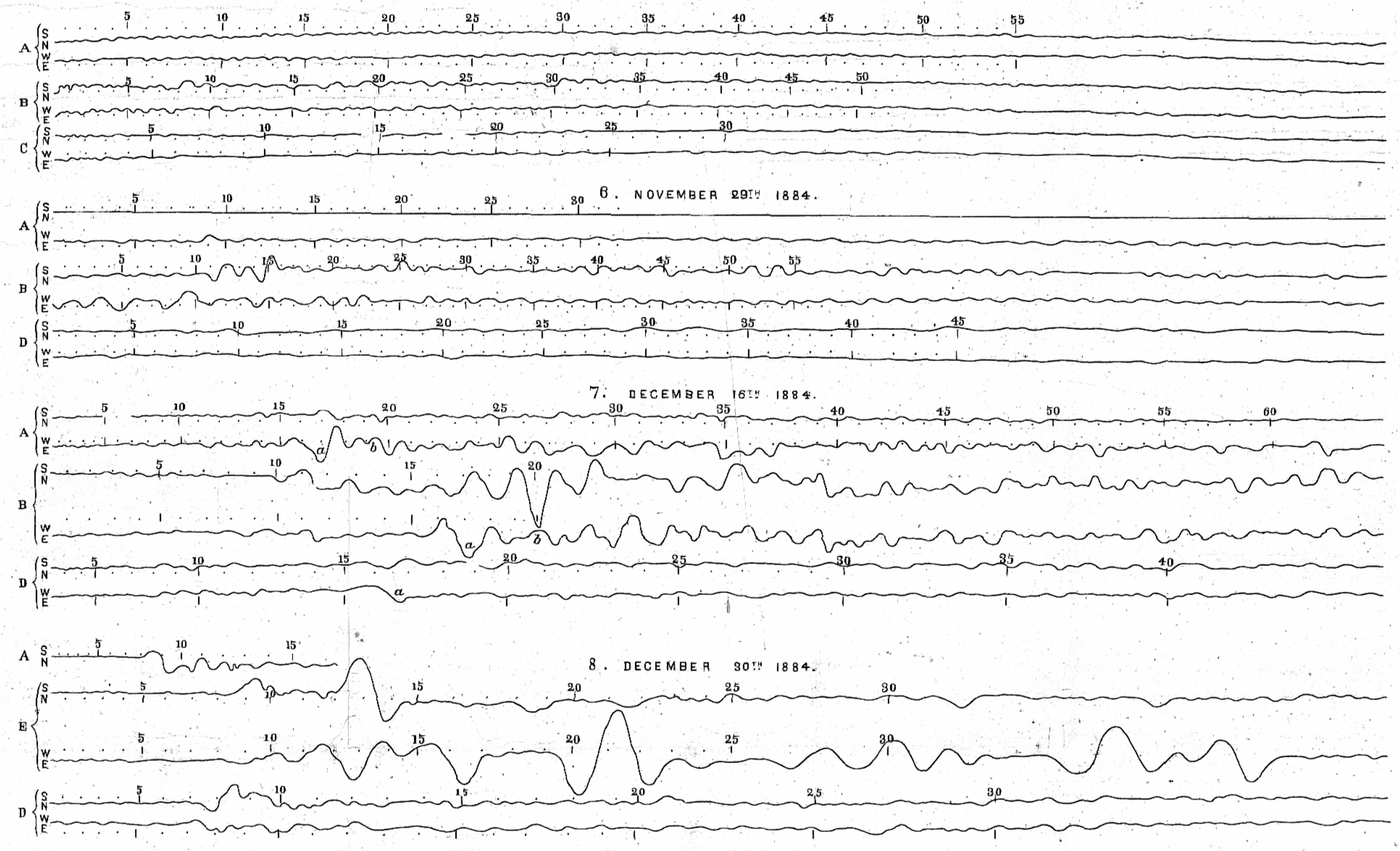


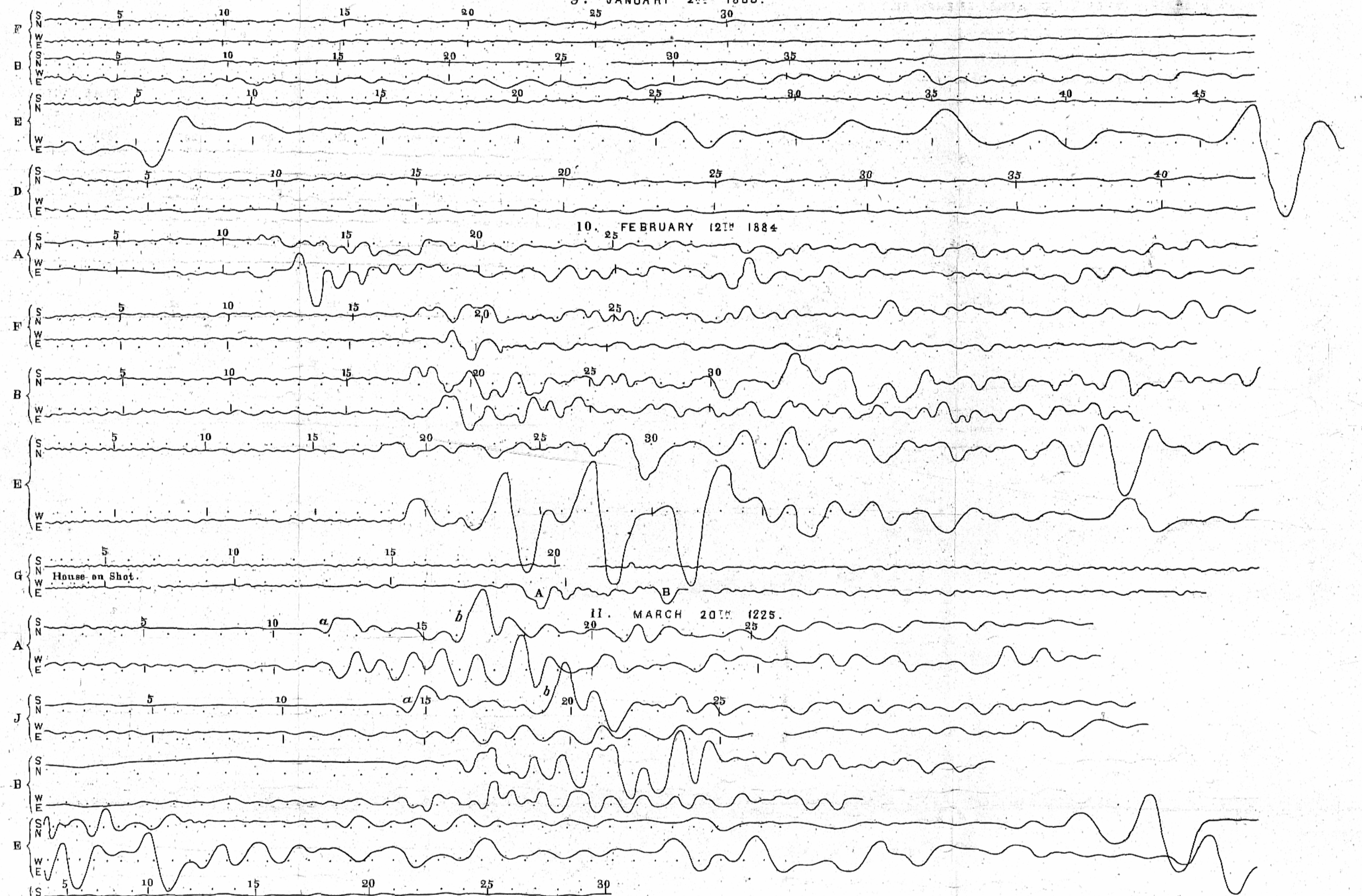
REFERENCE:

A.B.C.D.E.F.J. Stations on the surface of the ground.—
G. House standing upon balls.—
H. Station in pit; 10 feet deep.—
I. Starting Station.—

Scale: 170 Feet 1 Inch.

JOHN MILNE DELT.





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