Seismological Investigation.—First Report of the Committee, consisting of Mr. G. J. SYMONS *(Chairman)*, Dr. C. DAVISON *and* Professor J. MILNE *(Secretaries)*, Lord KELVIN, Professor W. G. ADAMS, Mr. J. T. BOTTOMLEY, Sir F. J. BRAMWELL, Professor G. H. DARWIN, Mr. HORACE DARWIN, Mr. G. F. DEACON, Professor J. A. EWING, *the late* Professor A. H. GREEN, Professor C. G. KNOTT, Professor G. A. LEBOUR, Professor R. MELDOLA, Professor J. PERRY, Professor J. H. POYNTING, *and* Dr. ISAAC ROBERTS.

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AT the Ipswich meeting of the Association it was resolved that the two committees which were studying vibrations of the earth's crust, viz., 'The Committee for investigating the Earthquake and Volcanic Phenomena of Japan,' and 'The Committee on Earth Tremors,' should not be reappointed individually, but that the whole subject should be referred to a new committee (consisting largely of the members of the old committees), which should be called 'The Committee on Seismological Observations.' This Committee now presents its first report, and in doing so desires to record its thanks to the Secretaries of the two old committees for having continued their work as joint Secretaries to the new one. Statements of what they have been doing form the bulk of the present report.

The Committee, however, thinks that it would be well, in this its first report, to state definitely what it hopes to accomplish, and how far it thinks that the British Association should go. It has long been an unwritten rule, that the Association should initiate work, but should not charge itself with its maintenance. That is precisely what your Committee desires. Now that it has been proved that any important earthquake is felt all over the globe, the Committee considers that arrangements should be made for the record and study of these movements. Your Committee believes that such records may prove as important as those of, *e.g.*, terrestrial magnetism, and, just as we have magnetic observatories in various parts of the world, so in its opinion should there be seismological ones. But, before advocating their erection, it is essential that a decision be arrived at as to the form and the degree of sensitiveness of instrument to be recommended.

This, and correspondence connected with the organisation of the system, is the work which the Committee desires to complete. Previous reports, and the appendices to the present one, show how much has been done in this direction, but the Committee wants to do much more. It wishes to place side by side four good patterns of instruments, and to compare and study their records. When this is done it hopes to receive the support of the Association in approaching Government with the view to the establishment of a limited number of instruments identical in sensitiveness, in this country, in India and in the Colonies, and of a small central office, at Kew or elsewhere, for co-ordinating and publishing the results. As far as the Committee can at present judge, the equipment of each station with complete apparatus for continuous photographic record would not exceed 100*l*. For the experimental work of the coming year the Committee have one instrument, and can have the use of another (constructed under a grant to Professor Milne by the Royal Society); it wishes to purchase two others, and will have to build piers, &c., and pay for photographic necessaries and an assistant to run the instruments, which, altogether, would probably cost over 200*l*. Your Committee thinks it desirable that to meet unforeseen items it should have 250*l*., but without 200*l*. the work cannot go on.

Report by Professor JOHN MILNE, *F.R.S.*

I. *Notes on Instruments which will record Earthquakes of Feeble Intensity.*

What we desire to record are preliminary tremors of small amplitude followed by quasi-elastic waves of comparatively large amplitude.

Within a hundred or two hundred miles of an origin, the former of these have periods varying between $\frac{1}{6}$ and $\frac{1}{15}$ of a second. At a great distance, say one quarter of the earth's circumference, these *may* have periods of from 5 to 12 seconds.

The latter near to an origin have periods varying between $\frac{1}{2}$ and 2 seconds, whilst at a great distance this period may be 20 seconds. As an average maximum velocity for the propagation of the preliminary tremors, we shall take 11 km. or about 7 miles per second. The large wave motion is propagated at about $\frac{1}{5}$ of this rate.

It has been found by trial that fifteen or twenty stations can be found on the globe, so that one of these shall be near to the antipodes of shocks originating on the west coast of South America, Japan or the Philippines, or the Western Himalaya, whilst six or seven other stations between one of these origins and its antipodes will lie at distances from each other of between one thousand and two thousand miles.

Because such an arrangement of stations is possible, we may take one thousand miles as being the minimum difference in distance between observing stations relatively to important seismic centres.

With the assumed velocity of propagation of 7 miles per second, the difference in times we expect to note will be about 143 seconds.

Because some stations will be at shorter distances from each other relatively to origins, I shall assume that instruments are required to note differences in time of 100 seconds.

Instruments.

The instruments at our disposal are :—

1. An Italian type like that of Vicentini which I call V.
2. Von Rebeur's Horizontal Pendulum „ „ R.
3. Milne's „ „ „ „ M.
4. Darwin's Bifilar Pendulum „ „ D.

Vicentini.—A pendulum of 100 k. at least 1·50 m. long. Light indices, multiplying motion eighty times relatively to the pendulum as a steady point, write on a moving surface of smoked paper. Two components of motion are recorded.

Von Rebeur.—A light horizontal pendulum weighing 42 grammes and 188 mm. in length, carrying a small mirror. Light from a lamp is reflected from this back through suitable lenses upon a slit in a box containing a drum carrying a bromide film.

Milne.—A horizontal pendulum with a boom 2 ft. 6 in. long, the whole apparatus within a case 4 ft. × 1 ft. 3 in. × 2 ft. The end of the boom is continuously photographed on a bromide film 2 in. wide. Because the lamp is within 6 in. of the paper, the necessary light is small.

Darwin.—A circular mirror with a bifilar suspension, so arranged that a slight tilt causes the mirror to rotate. This is immersed in paraffine. The instrument is exceedingly sensitive to change of level, but not to elastic tremors. The recording apparatus is photographic and very similar to that used by von Rebeur.

Accuracy as time-recorders (important).—The accuracy depends upon the rate at which the recording surface is moved, the method employed to mark time intervals upon its surface, and lastly the fineness or sharpness of definition of the record.

Assuming that on a diagram we can measure within ·25 mm., because

V	runs at	5	mm. per minute,	therefore	we can read	to within	3 seconds.
M	,,	1	,,	,,	,,	,,	15 ,,
R	,,	$\frac{1}{3}$	,,	,,	,,	,,	45 ,,
D	,,	$\frac{1}{6}$	,,	,,	,,	,,	90 ,,

By shaking M at known times, and comparing these times with times determined from the developed film, the difference between these is about half the expected error. Because this is probably true for the other instruments, the errors in 100 seconds may be,

V 1·5	seconds or	per cent.
M 7·5	,,	,,
R 22·5	,,	,,
D 45	,,	,,

Because time-intervals in V and M do not depend upon the clock driving the record-receiving surface, but are marked by an independent time-keeper, these errors should not exceed a small fraction of a second per hour. R and D do not share this advantage, the time being dependent upon a clock driving a drum or a broad film of bromide paper.

As a time recorder D is like R. Should the rate be made greater, it might involve an increase in light-source. The time intervals might also be marked by an independent clock.

V and M also present the advantage of yielding a diagram, the definition of which is much sharper than R and D. V is slightly better than M.

The M clock, which, however, only drives a film 2 inches wide, is so arranged that it can be instantly altered to drive the paper at a rate of about 6 or 10 in. per day, which, when recording diurnal waves, is sufficiently quick.

Equality in Adjustment (important).—If two or more similar instruments are not adjusted to have equal sensibility, they may commence to indicate with different phases of motion, and much of what is gained in the accuracy of the time scale is lost.

M and equivalent of R can be adjusted to have a close similarity in sensibility, and this is probably true of D.

With V, which writes by the friction of a pointer on a smoked surface, we have no experience, but from experience with its equivalent and a large experience with ordinary seismographs writing upon smoked surfaces, it seems likely that there would be great difficulty in obtaining equal sensibility, especially with instruments which were not side by side.

Even if absolute equality is attainable with a group of instruments, it should be remembered that instruments further from the epicentre will necessarily indicate a later phase of the movement than those close to it.

Sensibility.—All types record long period wave motion.

V gives an *open* diagram for movements, the period of which is not less than five seconds—that is of preliminary tremors at a distance from their origin. R and M show the presence of these, but of D we have no experience.

R and D give diagrams of large amplitude, but V has the best definition.

We do not know which instrument would at a given station commence to move the first. The probable order would be R, M, D, V.

Carts, trains and traffic, unless very near, do not affect any of the instruments.

D and V are probably not affected by 'earth (?) tremors' whilst M and R are affected, but the serious character of these in obliterating effects due to small movements has been greatly reduced.

D and R are most sensible to tilting effects like the diurnal wave, and therefore, unless we reduce their multiplication by reducing the distance between the mirrors and the film, they require a broad recording surface.

D is entirely unaffected by rapid tremors. The movement of the image during the passage of earthquake pulsations is absolutely steady, showing that the rapid vibrations superposed on the long waves (tiltings of the ground) are entirely quenched.

Installation and working.—V requires a strong support, like a solid wall, and vertically a space of 10 or 12 feet.

R and D require, as at present used, at least 12 feet horizontally, and unless we reduce their multiplication, a fairly strong light, and considerable isolation from the effect of loads. Six feet might be ample for R and D. The foundation for D costs 7*l.* or 8*l.*

M requires 4 feet horizontally, a small light, and moderate isolation.

Each instrument will require about ten minutes' time daily, and about one hour each week.

It is possible that the smoking and varnishing of a long roll of paper, as required by V, may be more troublesome than developing the photographic films of M, R, and D. The M film lasts one week. R and D require changing at shorter intervals.

Cost.—V, as made in Italy, *about* 20*l.*, but without timekeeper.
M, as made in England, 45*l.* with timekeeper.
R, as made in Strassburg, *about* 29*l.* without special timekeeper.
D, as made in England, *about* 50*l.* without special timekeeper.

Mr. Milne suggests to the Committee that they should buy the apparatus V and an R. After which V, M, R and D should be set up side by side. Let R and D be reduced in length to about 4 feet, and arranged to record on a surface similar to M. A broad recording surface requires a special clock to drive it, whilst it is expensive and troublesome to handle. When this is done, and experiments have extended over two or three months, we shall then be in a position to speak more definitely about the relative merits of these instruments as earthquake recorders.

II. *Observations with Pendulums T and U in the Isle of Wight,* 1895–96.

The Localities and their Geology.

The position of Shide Hill House, where instrument T is installed, is approximately 50° 41′ 18″ N. Lat., and 1° 17′ 10″ W. Long. It is near to the Shide railway station, at the foot of the western side of Pan Down, which is a portion of the chalk backbone of the Isle of Wight.

Up on the Down the chalk reaches to within a few inches of the surface. At Shide Hill House disintegrated chalk, which may have a thickness of about 6 feet, is met with at a depth of 3 feet. In front of the house, or towards the west, at a distance of about 150 yards at the other side of a small stream, there is a railway. In a N.E. direction, at a distance of

242 yards, there is a chalk quarry, where at certain fixed times blasting takes place.

At the back of the house within a few yards of the buildings in which the instrument is placed there is a lane down which on week days carts heavily laden with gravel pass.

Through the kindness of Mr. A. Harbottle Escourt, Deputy Governor of the island, I was enabled to establish a second instrument (U) within the grounds of Carisbrooke Castle. The foundation is similar to that at Shide, being a brick column built up from the chalk. This stands in a small room, one wall of which is the western wall of the castle. Towards the east it faces the Bowling Green.

This instrument gave its first records about June 22, but it was not in proper working order until the middle of July.

Shide lies at a distance of $1\frac{1}{4}$ mile in a N.N.E. direction from Carisbrooke. Mount Joy, which is 274 feet high, lies between the two places.

At Shide and continuing towards Carisbrooke the chalk ridge, which forms the backbone of the island, strikes E.S.E. to W.N.W., and dips at at a high angle approaching verticality towards the north. The central portion of this anticline has been removed by denudation, whilst its southern, which dips gently, can be seen in the Downs along the south coast.

The steep dip on the northern side of this anticline is a feature common to the folds of the continuation of these rocks. Sudden monoclinal folds are generally recognised as representing movements, which if continued result in faulting, and the home of faults is that of earthquakes.

The faults which are actually visible or inferred from the displacement of beds in the Isle of Wight are only seven or eight in number, and the throw of those, excepting the one supposed to exist a few miles east of Shide at Ashey, is but small (see 'The Geology of the Isle of Wight,' by H. W. Bristow, revised and enlarged by Clement Reid, and Aubrey Strahan, 'Memoirs of the Geological Survey,' 1889).

The structural and the stratigraphical conditions which I have personally observed at Shide and its neighbourhood are as follows. The chalk is so sharply tilted that it is reasonable to suppose that limits of its elasticity have often been exceeded. As a result of the pressure and metamorphic actions accompanying this distortion, the chalk has been so far hardened that when two pieces of it are struck together it has almost the ring of crystalline limestone, the flints if not broken into fragments have been brought together in patches, and have been so far fractured that by the application of light blows they fall in pieces. Siliceous matter has been deposited in veins, whilst slickensided surfaces in various directions apparently indicate that from time to time strain has been relieved by minor yieldings.

At Alverton chalk pit, which lies to the west of Carisbrooke, the chalk dips northwards at about 45°. Parallel to the dip the strike, and in intermediate directions the beds, are traversed by fractures which can be traced over lengths of 20 yards.

That these fractures are not mere cracks but are accompanied by displacement, and therefore have the character of true faults, is shown in one instance by the abrupt termination of a band of flint where it meets one of these lines, in another case, as also at Shide, it is shown by the smashing up of a mass of flint and the trailing out of the fragments of the same along the fractured face in a direction parallel to that of the striations. The last indications of displacement are the striations themselves.

The surfaces of these fractures are yellowish in colour, indicating that they have formed channels for subterranean water, but notwithstanding the solvent action accompanying such percolation the striations remain singularly clear.

The inference from this is that these fractures, which penetrate downwards to unknown depths, are of comparatively recent origin. In an upward direction they can be traced to the lower portion of the disintegrated chalk, but they cannot be traced through this into the overlying gravel and its thin capping of earth.

Had these overlying materials been as resistant to fracture as the hard chalk beneath them, it might be reasonably supposed that these fractures had been produced before the deposition of the overlying materials. In this instance, as in all other instances where deposits of a soft and yielding character overlie strata of a much harder nature, one of the usual arguments respecting the age of faults may fail. Very large earthquakes are occasionally accompanied by dislocation which reaches through the alluvium to the surface, but with the majority of such disturbances, as with the fractures which accompany a subsidence in a mine, the dislocations only extend upwards through rocks which are in a state of strain. It is therefore reasonable to suppose that the disintegrated chalk and its overlying soft materials could only be disturbed by faulting of an unusual character, and even in such instances, by settlement, the percolation of water and surface denudation traces of the same would be speedily obliterated.

In the majority of instances traces of fracturing and even faulting at considerable depths would not be visible near the surface. The faults which have been observed in the chalk of the Isle of Wight anticline and in the overlying tertiaries, up to the Hampstead beds, which have shared its movements, are in all probability the natural records of earthquakes of considerable magnitude.

Although geological evidence indicates that the Isle of Wight fold like those to the north of it was commenced in Miocene times, and was contemporaneous with movements which led to the building of the Italian peninsula and some of the largest mountain ranges in the world, actual earthquakes which have been felt in the Isle of Wight are but few in number. Dr. Groves, of Carisbrooke, who is familiar with the island and its history, has failed to meet with any accounts of such disturbances. Mr. Charles Davison, however, gives me the following list of shakings, which, although they did not originate in Vectis, may have been felt there—1734, November 5; 1750, March 19 and 29; 1755, November 1 (Lisbon); 1811, November 30; 1814, December 6; 1824, December 6; 1834, January 23 and August 27; 1853, April 1; 1884, April 22 (Colchester); 1889, May 29 (Channel Islands). On the opposite coast during the last two hundred years, on the authority of Mr. J. E. Sawyer, it may be concluded that a shock of some violence has on the average been felt once in every ten years. These were particularly noticeable about Chichester.

The reason that earth shakings never appear to have originated in the Isle of Wight, possibly lies in the fact that the strata in which it seems so likely that dislocations should occur is almost entirely composed of materials which are soft and yielding in their character, and therefore adjust themselves to new forms by crushing and gliding rather than by sudden fracturing.

The appearance and structure of the Isle of Wight anticline is that of a district in seismic strain, in which we might expect to find adjustments by intermittent and to some extent semi-viscous yielding. Later on it will be shown that horizontal pendulums founded in this chalk often exhibit sudden displacements, the cause of which is at present unknown. These are much too local in their character to be called earthquakes, and it seems likely that they will prove to be settlements beneath, or very near to, the foundations of the piers on which the instruments are placed.

The Instruments T and U and their Installation.

The instrument and the installation at Shide is designated by the letter T. Other horizontal pendulums of a similar type used in Japan are indicated by the preceding letters of the alphabet.

Instrument T differs from the one shown on p. 85 in the Report for 1895 in the arrangement of the boom, which at its outer end carries a small

FIG. 1.

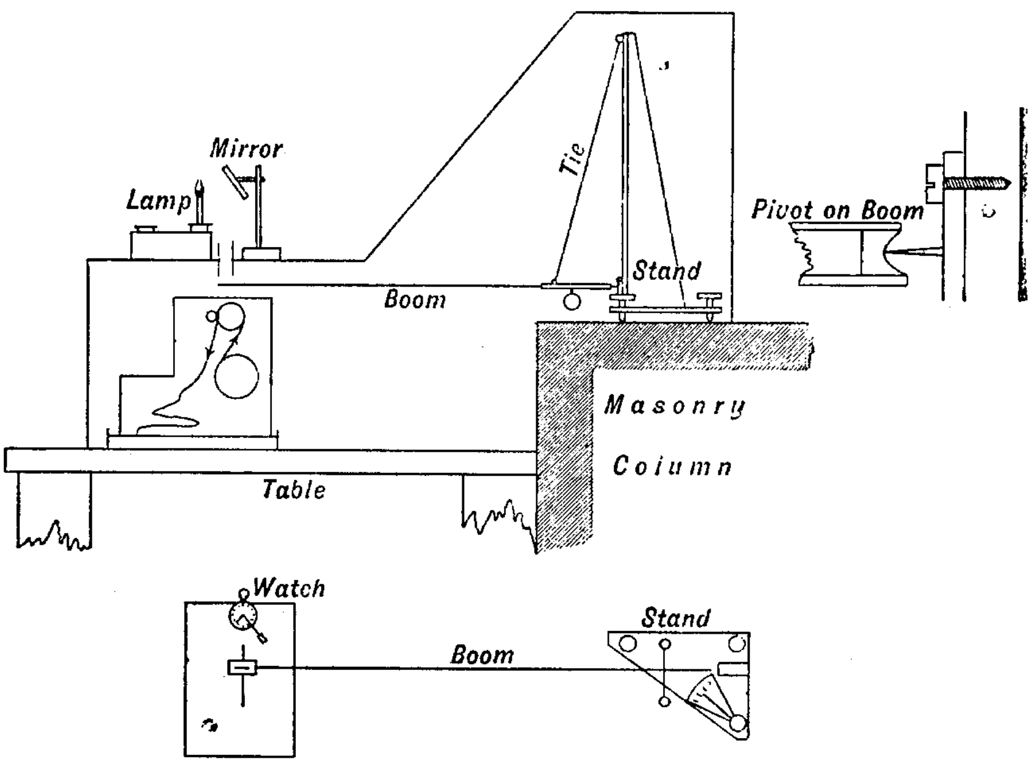


plate with *two* slits, one being large and the other small, the form of the bed plate, the balance weight being pivoted on an arm at right angles to the length of the boom, and the arrangement of a watch, the large hand of which every hour crosses the fixed slit in the box above the moving bromide to eclipse the light and give time intervals (see fig. 1).

Up to March 27, the boom constructed of varnished straw and reed was 2 ft. $5\frac{3}{4}$ in. long and weighed $\frac{3}{8}$ oz. The balance weight weighed $2\frac{1}{8}$ oz. With a period of 17 seconds a deflection at its outer end of 1 mm. corresponded to a tilt of 0″·71.

On April 24 this was replaced by an aluminium boom 3 feet in length, weighing $\frac{1}{2}$ oz. The balance weight weighs 8 oz. With a period of 31 seconds, a deflection of 1 mm. at its outer end corresponds to a tilt of about 0″·2.

The instrument stands upon the cement-covered top of a brick column, which is 1 ft. 6 in. square and 6 feet high. This rises freely in a pit 3 feet deep from a thin bed of concrete covering the surface of the disintegrated chalk. The sides of the column are oriented N S., and E W.

The building in which this is placed is an old stable built with brick, and sheltered by trees on its north, south, and west sides. From October 1895 the southern face of the column was covered with cement, which like the top was on that day coated with paint. The pit in which the column rises is filled with dry straw and hay, whilst for some months the column itself was wrapped round with a double thickness of thick felt.

About the end of June a second instrument which I call U was installed at Carisbrooke Castle. It was made by Mr. R. W. Munro, of Granville Place, King's Cross Road, London, W.C. In nearly all respects, excepting that of better workmanship, it is similar to the one at Shide. It stands on a brick column inside a building, one wall of which is the western wall of the Castle, facing the bowling green. With a period of 8 seconds its sensibility is such that 1 mm. deflection of the boom corresponds to a tilt of about 0″·5.

The cost of working one of these instruments, which includes benzine, bromide paper, used at the rate of 3 feet per day, and developers, is about 2*s.* 6*d.* per week. To wind and compare the watch, mark the bromide papers with a date, and to refill the lamp, which has to be done daily, occupies about 10 minutes. Changing and developing the papers once a week can be done in about 45 minutes. The time occupied to analyse a diagram depends upon its nature and the exactitude required in the necessary measurements. It may be 5 minutes or one hour. The walk to Carisbrooke and back takes about $1\frac{1}{2}$ hour.

Artificial Disturbances.—(Blasting, Train and Cart Effects.)

At a distance of 242 yards on the N.N.W. side of the instrument there is a chalk quarry, at which when the present observations commenced charges of powder of $\frac{1}{2}$ lb. and upwards were fired. Since October 1 the quantities of powder employed are said to have been reduced, and the times of firing the same confined to the half hours between 9 and 9.30 A.M. and 2 and 2.30 P.M.

Although I have several times had the opportunity of watching the instrument within 20 seconds of one of these explosions I never observed that any appreciable motion had been produced.

It may therefore be assumed that the instrument was not seriously affected by these operations. An assurance of this was obtained by comparing the following list of explosions very kindly made by Miss E. A. Evelegh, of Shide House, which is within 50 yards of the quarry and a railway cutting leading to the same, with the records of sudden displacements and swinging of the instrument :—

1895	H. M.		
August 30	7 20	P.M.	Heavy blast.
„ „	7 23	„	Moderate blast.
„ „	7 28	„	„ „
September 29	22 30	„	In the cutting
October 1	20 15	„	„ „
„ 2	19	„	„ „ double blast.
„ 3	22 10	„	„ pit, heavy blast.
„ 4	23 5	„	„ „
„ 4	23 25	„	„ „ 2 or 3 small blasts.
„ 8	19 20	„	„ „ double.
„ 9	21 55	„	„ „
„ 10	0 5	„	„ „
„ 10	18 25	„	„ „
„ 10	19 5	„	„ „
„ 10	23 20	„	„ „
„ 11	5 5	„	Very heavy double blast.
„ 11	21 55	„	In the pit.
„ 12	1 15	„	„
„ 13	20 15	„	„
„ 13	22 15	„	„
„ 14	2 0	„	„
„ 15	3 25	„	„
„ 15	22 0	„	„
„ 16	2 0	„	„
„ 16	20 45	„	„
„ 17	0 5	„	„
„ 17	21 55	„	Very heavy.
„ 18	21 40	„	„

The result of the comparison shows that in most instances no effect can be traced to the explosions. In one or two instances, however, a slight blur from ½ to 1 mm. in width has been the result.

The conclusion therefore is that the swingings recorded, which represent sudden changes in the inclination of the ground, have not been the result of blasting.

A few unusually heavy shots have, however, transmitted elastic vibrations as far as the instrument. These have caused the outer end of the boom to quiver but they have never produced a swing.

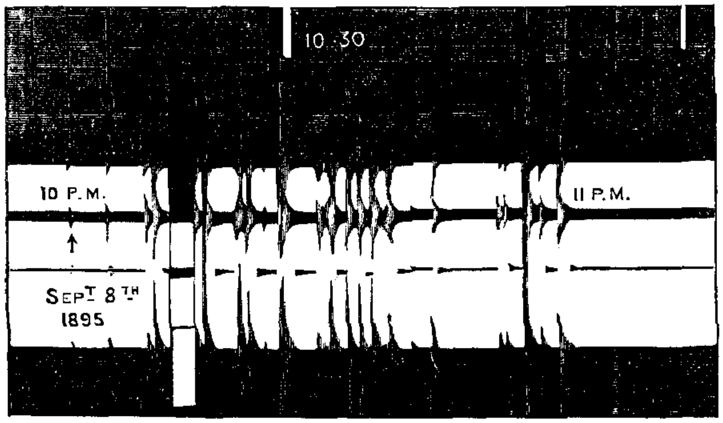
The true amplitude of most of these is in all probability only a fraction of a millimetre and unless carefully looked for would hardly be visible in the photogram.

A heavily laden cart passing at a distance of about 10 yards may produce a somewhat similar effect, but a light train at a distance of 150 yards does not appear to produce any effect.

Sudden Displacements and Earthquakes recorded at Shide.

By sudden displacements I mean movements like those shown in fig. 2. Usually, as here shown, they occur in groups, but now and then they occur singly. A similar appearance can be produced by gently pushing the pier carrying the instrument and then allowing the swinging boom to come to rest. Were they due to settlement in or beneath the pier, I should expect that they would be accompanied by permanent displacements which is seldom the case. A curious feature which now and then shows itself, and can be seen in fig. 2, is a permanent displacement of two or three minutes followed by a sudden return to the normal position. Minute spiders have sometimes found their way inside a case, but it is very doubtful that they should be able to cause the sudden disturbances shown and finally leave the boom in its normal position and free to swing. With records from nineteen installations in Japan I never remember observing movements of this character. Whatever may be the cause of these dis-

FIG. 2.—Displacements on September 10.



placements it is probably very local in its operation, and therefore they cannot be regarded as earthquakes.

The duration of a displacement is evidently the length of time it takes a pendulum which has been slightly deflected to come to rest. With a light boom this is about 1½ minute but with a heavy boom it may be 5 minutes. A group of disturbances may extend over 20 or 30 minutes. One group of 40 occupies 3 or 4 hours.

An earthquake originating at a distance has the appearance of fig. 3, which is probably the Shide record of the commencement of shocks which shook Cyprus on June 29, 1896.

Between August 19, 1895, and March 27, 1896, or during 202 working days, 485 sudden displacements and earthquakes were recorded.

In the following list the records referring to sudden displacements are those which succeed each other at short intervals, and are marked 'sudden' or 'strong.' Those which are followed by the remark 'slight' or 'moderate' may be due to actual earthquakes, the origins of which in some instances have been at great distances.

Records (August to November) marked **A** approximately correspond in time to disturbances noted by Professor Agamennone in the 'Bulletin Météorologique et Seismique de l'Observateur Impérial de Constantinople.' **T** refers to records published by Professor Pietro Tacchini (for September and November) in the 'Bollettino della Società Sismologica Italiana.' **G** refers to records received from Professor Gerland at Strassburg, and **K** to those from Professor Kortazzi at Nicolaiew.

These references, it will be observed, are very incomplete, and are only made up to the end of March 1896. In a subsequent report it is hoped that these will be completed, whilst the list itself will be extended up to date, and include the observations made at Carisbrooke.

The corrections are given in minutes and seconds, and are to be added or subtracted as indicated. From August 19 to October 27 the times after correction may have an error of ± 1 minute, but from the latter date onwards the errors should not exceed ± 5 seconds.

The uncorrected times are given in hours and decimals of the same—Greenwich mean time. Noon = 24 or 0 hours.

Under the column 'Remarks' the duration of disturbances is given in minutes and seconds.

Tremor storms and pulsations are *not* included in this catalogue.

Date	Correction		Time	Remarks
1895	M.	S.	H.	
August 19 .	+2	0	9·983 A	1m. 27s., sudden.
			15·883	" "
" 20 .	+2	0	7·783	" "
			9·383	" "
			Two displacements	The first is permanent to E. and the second partly back to W.
			9·516	1m. 27s., sudden.
			9·900	" "
			9·933	2m. 10s., "
			11·233 A	" "
			11·383	0m. 43s. "
			11·516 A	2m. 54s. "
			12·383 A	1m. 27s. "
			12·816	0m. 43s. "
" 28 .	.	.	11·5 to 12·5. Altogether nine strong displacements	From 1 to 2 m., sudden.
			14·5 to 15·0. Five strong shocks A	" "
" 30 .	.	.	0·5 to 4·0. There were three or four small displacements	
			9·560	About 1m. 30s.
			9·830	" "
			9·880	" "
			11·300	Slight
			16·220	Strong, 15m. earlier, two slight disturbances.
			16·463	Slight.
September 1 .	.	.	8·050 A	Moderate.
			11·214	19m.
			11·786	Slight.
			11·860	"
			21–24 A	Very slight disturbances. These may be blasts.
" 2 .	+0	37	1·30–5·30	Very slight disturbances. These may be blasts.
			9·645 A	Slight.
			11·930, the first of seven heavy displacements A	Total duration 53m., but after the second there is an interval of no motion of 17m.
			21 to 24	Slight, as if by blasting.
" 3 .	.	.	19·643	Heavy, 3m.
			20·643	Moderate, 1·5m.
" 4 .	.	.	2·000	Slight.
			14·380 A	"
			14·643	Strong.
			14·880	Slight.

TABLE I.—*continued.*

Date	Correction	Time	Remarks
1895	M. S.	H.	
		17·600, the first of five strong displacements	These are separate, but are included in 16m.; the third is strongest.
		18·000, the first of four displacements	The first is heavy. Total duration 18m.
		23–24	Blasting?
September 5 .	. .	0·2	Blasting.
		9·690	Moderate.
		12·240, the first of two displacements	,, Total duration 3m.
		12·790	Moderate.
		12·857	,,
		13·071	Strong.
		13·213	Moderate.
		13·500 (about)	Three very slight shocks.
		13·738	Strong.
		14 (about)	Two very slight shocks.
		15·095	Strong.
		15·548	,,
		20·357	Moderate.
,, 6 .	. .	9·000 (about)	,,
		21–24	Blasting.
,, 7 .	. .	10·762–13·000. There were fifteen large displacements	
		14·047	Moderate.
		11·095, first of five displacements	Total duration 20m., each one separate.
,, 8 .	. .	6·857	Displacement of 1·5m. and return.
		7·357	Displacement of 3m. and return.
		8·798, first of forty-two displacements which ended 12·014	Twenty-eight of these are large; there may have been more in the series, but at midnight the bromide film ended. Record ceases until September 18.
,, 19–24	. .	One or two slight sudden displacements but no shocks	
,, 25 .	. .	8·340 A	Moderate.
		8·454	,,
		10·928 A	Slight.
		13·400	,,
		23·5 to about 24·0 A	Six slight shocks amongst tremors.
,, 26 .	. .	4·691, followed by two others	Moderate.
		5·600 A	,,
		8·5	Strong.
		9·143	Slight.
		9·262	,,
		11·341	,,
,, 27 .	– 3 13	4·739	,,
		5·5 (about), three shocks T	The second large.

TABLE I.—*continued.*

Date	Correction	Time	Remarks
1895	M. S.	H.	
		7·120	Slight.
		7·430	
		7·5 to 8·5, six shocks	All moderate.
		9·5 (about)	Moderate.
		9·452	Two slight shocks.
		9·660	Moderate.
		14·320	,,
September 30 .	– 4 01	6 (about)	Two shocks, interval 1m.
		6·45 ,,	,, ,, ,,
		6·5 ,,	,, ,, ,,
		7 ,,	One shock.
		8 ,,	,,
		9·853, the first of thirteen	Total duration 28m.; the last are feebler and separated more widely than the first.
		21·80 (about) A	Moderate.
		22 ,,	Slight.
October 1 .	– 4 20	11·643, the first of five	Moderate, duration of series 1 hr. 5m.
,, 2 .	– 5 07	9·5–10·5 T	Four or five shocks.
,, 3 .	– 0 07	6·0, the first of seventeen displacements	Duration 1hr. 10m. The first commenced gently. The heavy ones are slight displacements.
		8·5 (about)	Slight.
,, 4 .	+ 3 58	6·4, the first of three displacements	Duration 8·5m.
,, 5 .	+ 4 46	10·0 (about)	Moderate.
,, 6 .	+ 2 47	12·5, the first of six displacements T	These occur in an interval of two hours.
,, 8 .	+ 3 31	10·140, the first of six shocks A	The first commences gently, duration 30m.
,, 9 .	+ 3 0	10·3 (about)	Slight.
,, 11 .	+ 11 7	5·09	Displacement.
		9·762	Strong, duration 3m.
		10·215	Moderate.
		22·333, the first of two shocks A	These are slight, and look like earthquakes from a distance.
,, 13 .	+ 9 41	9·0 (about)	Strong.
,, 15 .	+ 6 18	21 ,,	,,
,, 16 .	+ 4 3	4·25 ,, T	Moderate.
		5·5 ,,	Two shocks.
,, 18 .	– 0 47	8·75, first of three shocks	
		15·0 (about) A	Slight.
,, 19 .	– 2 51	0 to 3, there are seventeen slight disturbances T	These have the character of disturbances from a distance.
		8·25 (about)	Moderate.
		22·30 ,, V.T.G.K.	Strong displacement in the midst of tremors.
,, 21 .	. .	6·25 T	Strong.
,, 22 to 30	. .	. . . .	Lining case with felt. Heavy tremors often eclipse possible shocks.
,, 30 to Nov. 4	. .	No shocks	

TABLE I.—*continued.*

Date	Correction M.	Correction S.	Time	Remarks
1895	M.	S.	H.	
November 5 .	.	.	8·5 (about)	Strong.
			9·6	Moderate.
			22 (about)	Slight disturbance.
" 7 .	+ 1	30	9·93, the first of six A	Duration 55m. The first two are small, and the third is strong.
			16·8 (about)	Slight.
			20·5 "	Three slight.
			21·75 " the first of three	All slight.
" 12 .	− 1	0	7·45 (about)	Shock?
" 13 .	− 1	0	8·302, slight but followed by forty-four displacements A	Total duration, 3hr. 8m. The third shock or group of shocks has a duration of 6m.
			22·25 (about)	Moderate.
" 14 .	− 1	0	0·6 "	Slight.
			2·6 "	"
			4 "	A slight displacement.
			8·5 "	Four shocks, duration 10m.
			22·3 "	Six shocks, duration about 12m.
" 15 .	− 1	2	0·640, the first of six displacements	Duration 26m. the fourth is a group lasting 6m.
			3·6, the first of thirteen	Duration 1hr. 30m., the first shocks heavy, and those at the end slight.
			6 (about)	Two slight.
			6·5, three	Heavy.
" 16 .	− 1	5	3·9 (about) A	Slight blur.
			20·0 "	Three?
" 19 .	− 1	6	6·2 "	Displacement.
" 21 .	− 1	5	11·270, the first of three displacements A No more until Dec. 1	Duration 30m. All are displacements to the W. The return swing of the last takes 7m.
December 1 .	− 1	6	11·0 (about)	Slight, W. displacement.
" 2 .	− 1	7	10·0 "	" " "
" 5 .	− 0	44	11·5, the first of nine displacements	Duration 2½h.
" 9 .	− 0	42	0·25 (about)	Strong.
			2·0 "	Slight.
			3·25 "	Vibrations.
" 10 .	.	.	11·7 "	Slight displacement to W.
			0·42	
			14·7–15·0 (about)	Slight displacement to E. and then W. There are several of these up to 24h.
" 11 .	− 0	40	3·25 (about)	Slight displacement E.
" 14 .	− 0	30	19·0 "	Slight.
" 15 .	− 0	11	0·7 "	"
" 22 .	.	.	22·45 "	Moderate.
" 25 .	+ 0	41	19·0	Strong.
			19·634	"
" 26 .	+ 0	36	13·28 (about) A	Moderate.
			13·32 "	"
			19·15 "	Double shock.
			20·25 "	Moderate.

TABLE I.—*continued.*

Date	Correction	Time	Remarks
1895	M. S.	H.	
December 27 .	+ 0 31	3·50, 4·50, 4·45, 5·5, 7·5, 7·10, 7·12, 7·35, 7·38, 7·55, 8·0, 10·45, 15·50, 19·0, 20·45, 21·15	Approximate time of sixteen distinct displacements, the one at 10·45 commences gently.
„ 28 & 29	. .	. . . .	No records. Dec. 29 to Jan. 18 no shocks.
1896			
January 17 .	+ 0 33	22·45 (about)	Two vibrations.
„ 19 .	+ 0 36	1·0 „	Slight „
„ 22 .	+ 0 46	6·317	Strong.
		9·701, the first of five displacements	Duration 30m. The third is a displacement to E., and the fifth to the W.
„ 24 .	+ 0 55	3·350, the first of seven small displacements	Duration 20m.
„ 25 .	+ 0 59	22·50 (about)	Vibrations.
February 5 .	+ 1 16	2·5 „	Slight displacement.
		2·8 „	„ „
		3·140	Decided shock.
„ 6 .	+ 1 22	0·707	Slight.
		4·190	„
„ 8 .	+ 1 32	1·952	Decided shock.
„ 12 .	+ 1 33	2·0 (about)	Vibrations.
„ 21 .	+ 1 58	15·561	Strong.
		17·0 (about)	Three, the two second strong.
„ 24 .	+ 1 55	5·25 „	Slight tremor.
„ 28 .	+ 1 23	15·805, the first of four	Duration 30m.
		20·25 (about)	Slight.
		22 „ four displacements	Duration 8m.
March 1 . .	+ 2 10	9·0 (about)	Slight.
„ 15 . .	+ 2 0	4·000	Shock commences; max. 4m. later.
„ 16 . .	+ 2 0	5·548	First of three very slight shocks.
„ 22 . .	+ 2 53	1·191	First of two very slight shocks.
		2·309	First of five small shocks. Up to Mar. 27, when circumstances compelled me to cease recording, there were no more shocks.

After comparing 'sudden' disturbances and decided 'shocks' noted in July 1896 with similar records obtained at Carisbrooke, it is seen that these do not coincide in time. Therefore these movements, which appear to be so frequent in the winter, are extremely local in their action, and cannot be regarded as earthquakes. What they mean is at present unknown, and it will not be until two instruments have been installed near to each other that we can speak more definitely regarding their cause.

Because the lists given by Dr. Agamennone, which include, with the earthquakes of Turkey and Asia Minor, those of Italy and other European countries, are very full, we naturally expect to meet with approximate coincidences in time between some of these shocks and those recorded at Shide. As examples of these coincidences, the shock of August 19 at 9·983h. and that of August 20 at 12·383h. may be taken. These two shocks followed heavy disturbances which took place in Asia Minor by intervals of about 28m. 32s. and 32m. 32s. Taking the distance between the Isle of Wight and the western part of Asia Minor at $\frac{1}{15}$th of the earth's circumference and the velocity of a surface-wave at 2km. per second, these intervals of time should have been 23m. or 24m. The discrepancy of from 4m. to 8m. between what is observed and what would be expected might be explained on the assumption that the times noted in Asia Minor seem to be but roughly approximate. Several facts, however, indicate that many of the disturbances noted in the Isle of Wight, although they may agree in time with those catalogued by Agamennone, are not identical with the same.

The Isle of Wight *displacements* commence suddenly and succeed each other at widening intervals of time, both of which characters are suggestive of shocks having a local origin. Farther than this, although certain of them may have taken place at an interval of time roughly proportional to the distance of an origin when there has been a heavy disturbance, there are many in the same series where this proportionality does not exist. For example, although it has been shown that two out of the thirteen shocks of August 19 and 20 might be identical with shocks of those dates in Asia Minor, other shocks amongst the remaining eleven follow those in Asia Minor at intervals exceeding one hour, whilst some *precede* them. The important feature in the European and Isle of Wight records is the approximate coincidence in time of groups of shocks. On August 12 and 20 there were a succession of violent disturbances in Asia Minor, and on the same dates we find a marked set of disturbances in the folded and faulted strata of the Isle of Wight. For the same places the same phenomenon is repeated on November 13 and 14. In the Isle of Wight, on the former date, between 8.30 and 11.30 P.M., forty-four sudden tiltings were recorded, whilst in Asia Minor, between 9.30 on the 13th until the night of the 14th, there were violent shakings. Observations of this character suggest the idea that either unfelt earth-waves radiating from centre of violent activity disturb strata in a critical condition in distant places, or that the relief of strain in one portion of the globe cause readjustment in distant localities. Large earthquakes, like that of 1755, have apparently caused secondary earthquakes, whilst seismological chronology tells us that there have been periods when earthquakes have been more frequent throughout the world than at others.

Copies of this list have been sent to several of the principal observatories in Europe, where there is apparatus which might record similar disturbances. Up to date only three replies have been received, which are as follows :—

Dr. Eschenhagen, Potsdam.

1895. *Nov.* 9.—Schwingungen des Magnets von Lloyd's Wage (Magnet liegt Ost-West) nach den photographischen Curven ermittelt :—

	H.	M.	
Beginn	1	24.6	Mittl. Zeit Potsdam
Maximum	1	27.0	
Ende	1	27.8	

Amplitude sehr klein, c^a $\frac{1}{2}$ Bogenminute

Andeutungen von Schwingungen sind noch um:

1 31.0
1 34.4

1896. *Jan.* 9.—3 Stösse an Lloyd's Wage beobachtet:—

		H.	M.
(1)	Anfang	3	1.1 P.M. M. Z. Potsd.
	Maxim.		1.8
	Ende		2.9
	Amplitude		1 Bogenminute
(2)	Anfang	3	5.8
	Maxim.		6.9
	Ende		8.9
	Amplitude		0.8 Bogenminute
(3)	Anfang	3	11.0
	Maxim.		12.6
	Ende		13.9
	Amplitude		0.5 Bogenminute

1896. *März* 4.—Mehrere Stösse bei allen drei Komponenten beobachtet:—

—	I. Declination	(Bifilarmagnet) II. Horiz. Comp.	III. Wage
	H. M.	H. M.	H. M.
(1) Anfang . .	5 44.8 A.M.	5 36.2	5 42.9
Maxim. . .	46.2	Schwache Bewegung	Schwache
Ende . .	47.7	5 43.7	Bewegung
Amplitude .	c[a] .1′		—
(2) Anfang . .	5 48.3	—	5 45.3
Maxim. . .	49.9	Gleichmässige Schwingungen	46.3
Ende . .	51.7	5 50.9	48.0
Amplitude .	c[a] 1.0′	0.5′–1.0′	0.5′
(3) Anfang . .	5 55.1	5 54.7	5 48.5
Maxim. . .	5 58.3	Schwache	—
Ende . .	6 2.0	Bewegung	—
Amplitude .	c[a] .1′	—	—

Alle Zeitangaben sind nach mittlerer Zeit Potsdam gemacht (0h. 52m. 15.4s. Zeitdifferenz gegen Greenwich). Dieselben sind auf $\frac{1}{4}$–$\frac{1}{2}$ m. sicher. Die hier vorliegenden Beobachtungen zeigen leider keine Coincidenz mit den dortigen.

Potsdam, 1896, Juni 23.

On November 2 and January 9 shocks were not recorded at Shide, whilst on March 4, at the hours specified, the instrument was dismantled, and a felt lining removed from the case.

Professor G. Agamennone, Constantinople.

C'est avec grand plaisir que j'ai reçu la liste des secousses sismiques que vous avez enregistrées à Shide du 17 août 1895 jusqu'au 27 mars 1896.

Je n'ai pas manqué de les confronter avec celles que j'ai déjà publiées ou que je publierai sous peu dans le 'Bulletin Météorologique et Sismique' de Constantinople, bulletin que je m'honore de vous envoyer et que, je l'espère, vous devez régulièrement recevoir.

D'après ce qu'il résulte de cette comparaison je n'ai pu y trouver aucune relation qui soit bien sûre, un intervalle de temps remarquable se trouvant toujours entre les commotions sismiques d'Orient et les perturbations indiquées par vos instruments, eu égard, bien entendu, aux diverses longitudes.

Une différence moindre se montre seulement pour la secousse du 19 août 1895, laquelle fut indiquée dans votre observatoire à 10^h 1^m du matin, tandis que $\frac{1}{4}$ d'heure plus tard un désastreux tremblement de terre ravagea la ville d'Aïdin et ses alentours en Asie Mineure.

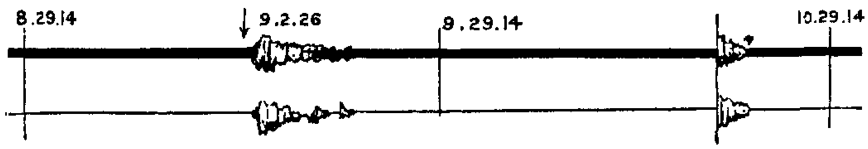
Je porte, enfin, à votre connaissance que le 29 juin passé, vers 11ʰ ½ du soir (t. m. Constantinople ?) une forte secousse sismique à eu lieu sur la côte de la Syrie et s'est fait ressentir aussi avec une grande intensité à Larnaca (Chypre).

6 juillet 1896.

As Professor Agamennone remarks, my record for October 19 precedes the Aïdin Disaster by about 15 minutes, but it follows the fourth and heaviest shock felt at Bouladan, at about 9h. 44m. 6s. G.M.T.

The Cyprus shock of June 29 was recorded at Shide (see fig. 3).

FIG 3.—June 29, 1896. Cyprus.



Dr. Adolfo Cancani writes that the Shide records do not correspond to those at Rocca di Papa.

Earthquakes recorded in Europe, followed by disturbances at Shide, Aug. 19–Nov. 30, 1895.

Date	Locality	Character of Shocks	G.M.T. at Locality	G.M.T. at Shide	Diff. in G.M.T.	Character at Shide
1895			H M. S.	H. M. S.		
Aug. 1	Bouladan .	Heavy	9 44 6	10 1 0	17 min.	Sudden
„ 20	Patras .	—	10 33 36	11 16 0	42 „	„
„ 20	Aïdin .	Heavy	12 4 6	12 25 0	21 „	„
„ 28	Zante .	Slight	14 14 6	14 30 0	16 „	Strong
Sept. 1	Messina .	—	8 0 0 (about)	8 2 0	2 „ (about)	Moderate
„ 1	Laibach .	—	10 8 0 (about)	11 1 0	53 min. (about)	„
—	Laibach .	Strong	9 12 6	9 38 0	26 min.	Slight
—	Zante .	Light	13 4 6	14 23 0	59 „	„
„ 25	Zante .	—	7 47 6 (and at night)	8 20 0	33 „	Moderate
„ 26	Zante .	Feeble	5 11 6	5 36 0	25 „	„
„ 27	Spoleto .	—	4 9 6	4 43 0	34 „	Slight
Oct. 6	Florence .	—	11 22 34	12 30 0	7 „	—
„ 8	Laibach .	—	night	10 8 0	—	First of 6 commence gently
—	Zante .	Strong	11 4 6	10 24 7	20 „	Light
„ 16	Giano dell' Umbra .	—	3 50 0	4 19 3	29 „	Moderate

Out of these fifteen shocks, if we make an allowance of a few minutes in the accuracy of the times in the fourth column, then there are twelve of them recorded at Shide at about the times we should expect them to have reached that place. Two of the first three shocks which were 'sudden' at Shide took place when we might expect earth-waves to have reached that place from localities where there had been heavy disturbances.

Notes on Special Earthquakes.[1]

October 19, 21*h.* 30*m.* *G.M.T.*, 1895 (*Strassburg*).—The following note is derived from a sketch of the photographic trace sent to me by Dr. Gerland, of Strassburg. This sketch shows the movements which took place in a von Rebeur-Paschwitz pendulum on the morning of October 20.

About 10 A.M. (S.M.T.) there were preliminary tremors, lasting about five minutes. These were followed by strong movements, reaching thirty or more millimetres, which continued until about 11.30, during which time the pendulum was displaced by four steps towards the south. From this time the movement died out, but slight movements are observable until after 1.30 P.M. The duration of the disturbance was therefore at least $3\frac{1}{2}$ hours.

Padua.—Observations made with the pendulum apparatus and multiplying indices of Professor G. Vicentini:—

	H.	M.	S.
Commencement	10	29	44
End	11	55	45
Duration	1	26	0

These times are probably mean European time.

Nicolaiew (Professor Kortazzi).—Observation with a horizontal pendulum:—

	H.	M.	S.
Commencement N.M.T.	21	30	0

Shide, Isle of Wight (Milne's Pendulum).—Unfortunately this disturbance occurred in the midst of a tremor storm. Its commencement and end are therefore lost.

Strong movements occurred at 22h. 24m., 22h. 27m. and 22h. 32m. G.M.T.

Reducing the observations to Greenwich mean time we obtain:—

	Commencement			Maximum			
	H.	M.	S.	H.	M.	S.	
Strassburg	21	28	55	22	28	55	about
Padua	21	29	44	21	43	44	"
Nicolaiew	21	29	51				
Shide	unknown			22	30	0	"

These records show that three types of instrument have each been sufficiently sensitive to record the same disturbance.

September 4, 5, 7 *and* 8.—It will be observed that on these days, from which it must be noted September 6 is omitted, when there was practically no movements, that shocks were very frequent. Dr. Gerland of Strassburg writes me that on these days there were many small shocks, and a tendency for the pendulum to move towards the south.

June 15, 1893.—On the above date Professor Vicentini, at Padua, recorded disturbances, commencing at 10.45 A.M. G.M.T., which reached a maximum at about 11h. 14m. P.M., ending about one hour later.

At Shide a disturbance commenced at 10.30 A.M. G.M.T., but as the instrument was dismantled at 11.30 the record is incomplete.

If we allow forty-five minutes for a disturbance to travel from Japan to Europe, and nine hours as the difference in time between Greenwich and Tokio, then in Japan mean time the earthquakes and sea-waves, which

[1] See Appendix.

resulted in the loss of about 30,000 lives, took place on June 15 at about 8.30 P.M. Until July 11, when we learned that the destruction had taken place on June 15, the impression received from telegrams was that it occurred on June 17. We now know that the information derived from seismographs was correct, whilst that published as telegrams in our daily papers involved an error of two days.

June 29 *to July* 4, 1896.—At about 11 P.M. on June 29 there was a violent shock in Cyprus, which was followed by a series of others.

An alarming shock was felt at 8.25 A.M. on July 3, and others at noon, 12.38 P.M., 2.52 P.M., and 3.22 P.M.

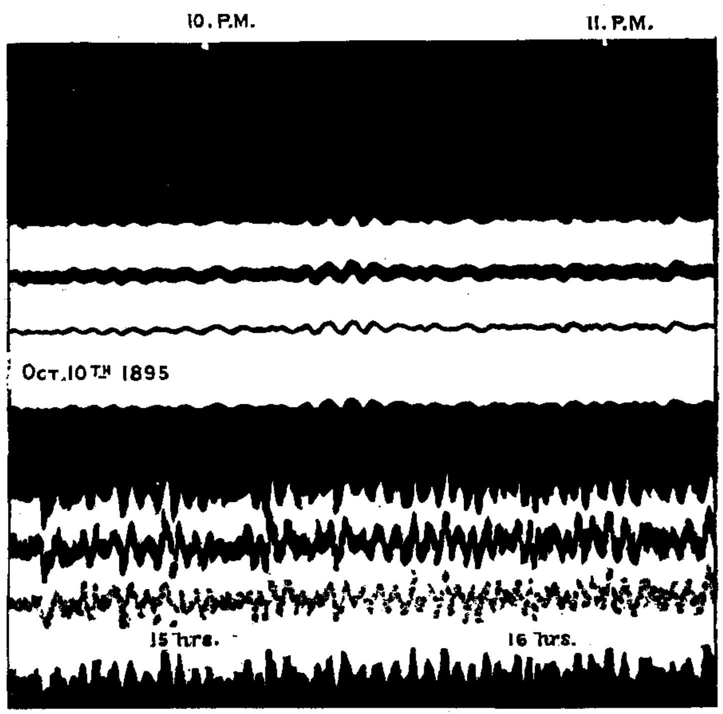
On these days many small shocks were recorded at Shide. Assuming a difference in time between Cyprus and Greenwich of 2h. 12m., the above times and dates in G.M.T. are as follows, and are placed side by side with the observations made at Shide.

	Cyprus				Shide			
	H.	M.	S.		H.	M.	S.	
June 29 . .	8	48	0	severe	9	02	26	continuing to 9 24 45
July 2 . .	18	13	0	„	18	51	29	
„ 2 . .	21	48	0	moderate	not recorded			
„ 2 . .	22	26	0	„	„	„		
„ 3 . .	0	40	0	„	„	„		
„ 3 . .	1	10	0	„	„	„		

Tremors and Pulsations.

In the following table the more or less continuous, regular, and irregular swingings or repeated tiltings which have been observed are

FIG. 4.—Commencement and Growth of a Tremor Storm.

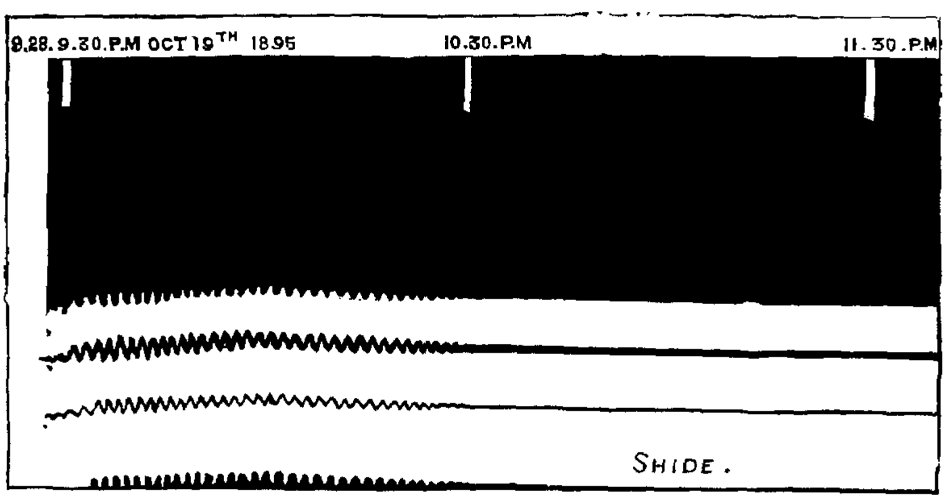


arranged chronologically. The numbers in brackets indicate the range of motion expressed in millimetres. The first entry for August 18 means that between 18 and 19 hours the pendulum was swinging through a range of half a millimetre. On August 23 the motion was continuous for the whole twenty-four hours, and the extent of motion was 10 millimetres. On days that are omitted, unless there are remarks to the contrary, the pendulum was at rest. Although the natural period of

FIG. 5.—Tremor Storm and Deflection.

the pendulum was 17 seconds, it will be noticed that sometimes its period exceeded 5 minutes, while periods of 1½ minute are common. Irregular and comparatively rapid swingings of the instrument are called tremors. Some of these are apparently due to the establishment of air currents within the case of the instruments, while others seem to have their origin in actual movements of the supporting pier.

FIG. 6.—Pulsations at Shide.



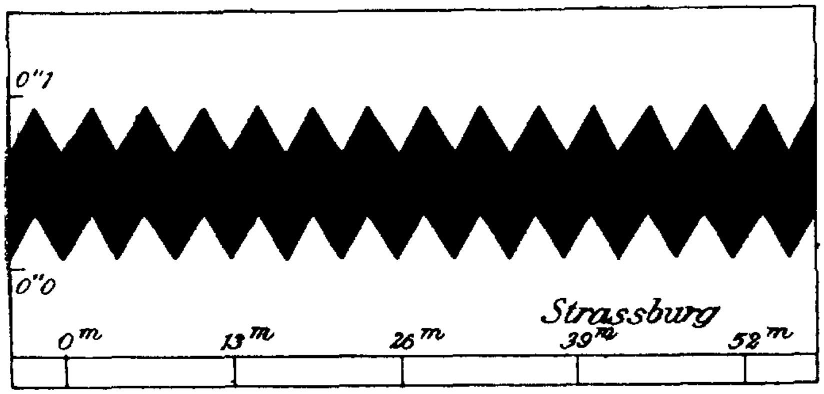
Pulsations are slow movements which are regular in the period and amplitude on the photogram, having an appearance like that produced by a tuning fork recording its vibrations on a moving smoked surface. These pulsations are referred to as such, or as waves. Often they are distinct from tremors, but at other times they lead up to tremor storms, and in such cases it becomes difficult to distinguish between pulsations and tremors.

Fig. 4 shows the commencement of a tremor storm at 10 P.M. on October 10, with long period irregular waves. At 15 and 16 hours it will be noticed that there has been a great increase in amplitude.

Fig. 5 shows a portion of a heavy tremor storm with a rapid tilt on October 17.

Figs. 6 and 7 show pulsations at Shide, commencing on October 19,

FIG. 7.—Pulsations at Strassburg (Paschwitz), enlarged ten times.



at 9.30 P.M., and pulsations at Strassburg magnified 10 times. The latter are reproduced from the work of von Rebeur-Paschwitz because they are identical with records often obtained in Japan.

TABLE II.

Date	—	Remarks
	1895.	
August		
18	18 to 19 (·5), 21 to 24	—
19	0 to 4 (1)	—
20	0 to 3 (·5)	—
23	0 to 24 (10)	Windy. Trays of $CaCl_2$ put in the case. When this was taken out the heavy tremors ceased. This was done three times.
24	0 to 24 (10)	
25	Heavy tremors	
26	"	
27	"	
28	"	
29	"	
30	17 to 20 (1)	—
Sept.		
2	5 to 8 (2)	—
4	16 to 20, max. 18 (3)	—
8 to 19	—	No records.
25	23 to 24 (·5)	Heavy rain and thunder.
28	2 to 4 (1)	—
28	20 to 23 (4)	—
29	18 to 22 (3)	Period 4m. 18s.
October		
1	19 to 24, max. 22 (5)	—
2	0 to 3.30	Tremors die out.
2	3 to 8.30, slight	Very windy on the 3rd, and no tremors.
2	9.30 to 24, max. 17 (6)	—
4	10.30 to 23, max. 16 (5)	Periods 3m. 20s. to 4m.
6	12.30 to 18.30	All tremors for the preceding week have long periods.

TABLE II.—*continued.*

Date	—	Remarks
October		
7	Slight	—
8	„ 7 to 18	Rain at night.
8	18 to 24, max. 23 (10)	Period 3m.
9	0 to 5 slight, and slight all day	—
9	19 to 23 (5)	—
10	8 to 24, max. 18 (8), at 10 (2) with 2m. period	Period is shorter. 1·5m. at end of storm.
11	6 to 24, very slight	—
13	14 to 21, max. 18 (5)	Period reaches 5·4 m.
14	18 to 19, slight	—
15	21 to 24, „	—
16	1 to 7 (3)	Sudden increase from 2 mm. to 7 mm. in tremors after opening case at 7.45 P.M.
16	7 to 24, max. 18 to 21 (15)	Period 1m 25s. to 2m. 50s.
17	0 to 6	Tremors die down.
17	9 to 24, max. 12 to 20 (6)	Period at 9h. about 2m. 50s., but decreases at end of storm. *Cold at night.*
18	0 to 24, slight	Max. of 2·5mm. after opening case at 21. Dies out as regular pulsations of ·5mm. and period 1m. 25s.
19	4 to 5, two groups of 10 waves each (1)	These are good examples of pulsations. The latter has 34 waves. Period 1m. 24s. to 2m. 7s. Max. range 2mm.
19	8 to 10, 34 waves per hour	
19	13 to 24, max. 21 (5)	—
20	0 to 3	Die out.
20	4 to 5, two groups of 9 waves each	—
20	10 to 24, max. 20 (5)	Commence as pulsations.
21	0 to 8	Slight.
21	4 to 6, groups of slight regular waves	—
21	8 to 24, 20 (5)	Increase after opening case at 20.
22	0 to 11	Reach 15mm. when the pendulum is deflected and they stop suddenly.
22	12 to 20 (2)	
22	20 to 24 (15)	These large tremors commence after opening box.
23–24	Heavy tremors (10 to 15)	No $CaCl_2$ in box.
24	—	Box painted inside, and face and top of column covered with cement.
27	Heavy tremors (10 to 15)	These continue even with doors of case open.
30	„ „	
30	—	Completely covered inside of case with thick felt and tremors cease.
Nov.		
2	11 to 22 (1)	—
5	22 (·5)	—
8	22 to 24, slight	9h., door slightly opened; closed it at 7h. on the 11th. On the 10th it was very stormy all day and no tremors.
9	0 to 9, „	
9	1 to 2, irregular and slow	Period 5·6m.
9	10 to 22 (1)	—
11	5 to 24, max. 14 to 24 (5)	Become marked after closing door at 7 P.M. Period 2·8m., but this is shorter at end of storm.
12	0 to 6	Storm dies out.
12	6 to 7	A calm day.

TABLE II.—*continued.*

Date	—	Remarks
Nov.		
12	7 to 24, max. 13 to 19 (5)	Period often 2·8m.
13	0 to 3, slight	2.30, pulsations 6 waves, each ·5mm. The column was felted and box filled round with straw.
13	3 to 24	Now and then very slight irregularities.
14	10 to 14	" " "
14	14 to 24, max. 18 to 20 (3)	Period 1·4m. Breeze, cloud, rain.
16	16 to 24, max. 19 to 21 (2)	Period of irregular waves reaches 5·6m. High wind in morning and no tremors.
17	0 to 5, slight	Dull, showers, calm.
17	5 to 24, max. 9 to 14 (4)	Irregular waves reach 4·2m. At 23.30 a very heavy storm commences suddenly. Frosty.
18	0 to 2.30 (5)	Period 2·8m. and fairly regular.
18	2.30 to 24	Dying out slowly.
19 to 21	No tremors	Gauze put over door.
22	16 to 24, max. 22 to 24 (3)	Period 1·4m. Calm.
23	0 to 24, max. 12 to 24 (3 to 4)	Period 1·4m. Fine.
24	0 to 8	Tremors die out. N. wind.
24	8 to 24, slight	Dull. Strong wind at night.
24	0 to 16, very slight	—
24	16 to 24 (1)	—
26	0 to 16, very slight	Dull, calm.
27	0 to 14, no tremors	Rain.
27 to 30	Up to 16 hours no tremors	On 29th took gauze off.
27 to 30	16 to 4 (1)	—
Dec.		
1	9 to 24, max. 18 to 22 (2 to 3)	Fog in morning.
2	0 to 3, slight	Fine.
3 to 5	No tremors except 23 to 24, slight	Dull and damp. Strong wind on the 4th and 5th.
6	0 to 24, from 3 violent	High wind at night.
7	0 to 24 (10), violent	Fine, windy.
8	0 to 24 (10), violent; die out from 19 hours, but increase slightly after opening door	Calm.
9	No tremors	Dull.
10	10 to 24, slight	Fog, calm.
11	22 to 24, "	" "
12	1 to 3, "	Heavy S. gale from 10 A.M.
12	3 to 10, "	—
12	10 to 24, max. 18 to 20 (5)	—
13	0 to 24, max. 9 to 22 (4)	Moderate N. wind.
14	No tremors	Fog, calm.
15	8 to 24, max. 18 (2)	Opening door at 21 increased the tremor. Dull, no wind.
16	0 to 8 (3 or 4)	At 8.45 door was closed and tremors are greatly reduced.
16	8 to 24 (1 or 2)	Rain.
17	0 to 24 (1)	Dull, fine.
18	0 to 24 (1)	Slight increase of tremors at night. Dull, drizzle.
19	0 to 24 (4 or 5)	Started by opening the door. Dull and calm.
20	4 to 24, max. 18 to 24 (2)	Calm, tremors reduced from 3 to almost zero by putting in wind guard.
	0 to 24 (2)	Period 2·8m. Fog, calm.
	0 to 24, no tremors	Fine, breeze.

TABLE II.—*continued.*

Date	—	Remarks
Dec.		
23	No tremors	Dull, S. wind.
24	23 to 24, slight	Rain, S.E. wind.
25	0 to 24 (2)	Period 2·8. Little snow.
26	0 to 8, slight	Drizzle.
26	8 to 24, no tremors	Dull, calm.
27	14 to 17, slight	" "
28	No tremors	Dull, rain.
29	"	Clock sent to be cleaned.
	1896.	
Jan.		
4	0 to 24 (·5), max. 18 to 20 (1)	Period 2·8m. Calm.
5	0 to 24 (·5 to 1), max. 15 to 24 (1·5)	Period regular, about 2·8m. Fog, calm.
6	0 to 24 (1)	Regular character.
7	0 to 24 (1)	" "
8	18 to 24 (1)	" "
9	0 to 24 (1)	" "
10	0 to 18 (·5)	" "
		From 5th to 10th no wind.
11	No tremors	Dull, calm.
12	"	" "
13	"	Fine.
14	"	Dull, calm.
15	"	S.W. wind, sun, cloud.
16	"	Dull, windy at night.
17	"	Fine, calm.
18	"	Dull, calm.
19	0 to 9, no tremors	" "
19	9 to 24 (10), max. 13 to 24	Calm, drizzle.
20	0 to 24 (3)	Period 1·25m. to 2m. Fine, hard frost.
21	0 to 9 (2)	Dull, damp, calm.
21	9 to 10, no tremors	—
21	10 to 24 (1)	Regular.
22	8 to 22 (·5)	Dull, calm.
23	Occasionally very slight and regular	Calm, fog.
24	No tremors	Calm, but wind rising at night.
25	0 to 24, no tremors	S.W. wind all last night. Rain.
26	No tremors	Dull, calm.
27	"	Drizzle.
28	0 to 5, no tremors	Fine. Frost at night.
28	5 to 24, max. all night (10)	—
29	0 to 24, max. at night (5)	Frosty, calm.
30	0 to 24 (3)	White frost, calm.
31	0 to 10 (1)	Dull, calm.
31	10 to 24 (2)	—
Feb.		
1	0 to 10, slight	Dull, calm.
1	10 to 24 (1)	—
2	0 to 6, slight	Calm, fine.
2	6 to 24, max. 10 to 16 (3)	—
3	0 to 17, no tremors	S.W. breeze, dull.
3	17 to 23, slight	—
4	0 to 11, no tremors	Dull, calm.
4	11 to 22 (1), max. 16 to 21	—
4	22 to 24, no tremors	—
5	0 to 24, no tremors	Dull, calm.
6	" "	Wind in early morning, calm.

TABLE II.—*continued.*

Date	—	Remarks
Feb.		
7	0 to 13, no tremors	Dull, damp. At night S.W. breeze.
7	13 to 21, max. 19 (2)	—
8	0 to 24, no tremors	S.W. breeze, fine. At night heavy wind.
9	0 to 22, no tremors	Drizzle, calm.
9	22 to 24, slight	—
10	0 to 22, no tremors	Fog, calm.
10	22 to 23, small pulsations (·5)	Period 2·8m. to 5·6m.
11	0 to 10, no tremors	Fine, calm.
11	10 to 12, pulsations (1), which lead to tremors	Period 4·2m.
11	12 to 24, slow tremors (2)	—
12	Slight tremors at night	Fine, calm.
13	0 to 19, no tremors	Fog, calm.
13	19 to 24, tremors or pulsations (1)	—
14	0 to 16, no tremors	Dull, calm.
14	16 to 24, slow tremors, max. 22 to 23, (2)	—
15	0 to 18, no tremors	Fine, calm.
15	18 to 24, slow tremors (2)	—
16	0 to 6, slow tremors (2)	Period 2·8m. to 4·2m.; stop by opening door at 6·33, but in 1½ hour recommence.
16	6 to 7.30, no tremors	—
16	7.30 to 24, max. 19 (2)	Dull, damp.
17	0 to 2 (2)	Calm, dull, cold.
17	2 to 4, no tremors	—
17	4 to 24, max. 17 to 24 (2)	Period 1·4m. to 1·2m.
18	0 to 3 die out	Fog, calm.
18	3 to 24, no tremors	—
19	0 to 24, no tremors	Calm, sunshine, cloud.
20	0 to 24, no tremors, but a trace of tremors at 22	Dull, sea breeze.
21	0 to 24, no tremors, but a trace 21 to 24	Bright sunshine.
22	0 to 6, no tremors	Dull.
22	0 to 24 (increase up to 5)	Period at first 4·2m.
23	0 to 3, die out	Fine, frosty last night.
23	3 to 5, no tremors	—
23	5 to 24 (increase up to 3)	Period 1·4m. to 2·8m. Frosty at night.
24	0 to 1, die out	—
24	1 to 6, no tremors	—
24	6 to 24, max. 18 to 20 (2)	—
25	0 to 4, die out	Frosty last night.
25	4 to 5, no tremors	—
25	5 to 24, max. 17 to 24 (3)	—
26	0 to 8, die out	Cold, frosty, calm.
26	9 to 24, slight, max. 20 to 21 (1)	Slight pulsations in groups of 3 to 8 at intervals of 30 minutes.
27	0 to 24, no tremors	Fine, calm.
28	,, ,,	Fine, stormy, N.W. wind.
29	,, ,,	Dull, S. wind.
Mar.		
1	0 to 13, no tremors	Dull, S. wind.
1	13 to 24, slight	—
2	0 to 24, no tremors	Fine.
3	No record	Removed felt lining from box.

TABLE II.—*continued.*

Date	—	Remarks
Mar.		
4	0 to 24, max. 16 (1)	Stormy.
5	0 to 3, slight	Fine, breezy.
5	3 to 21, no tremors	—
5	21 to 24, slight	After opening door.
6	0 to 2, slight	Dull, S. wind.
6	3 to 24, no temors	—
7	0 to 24, no temors	Rain, calm.
8	,, ,,	Dull, W. wind.
9	0 to 14, no tremors	Dull, S.W. breeze.
9	14 to 24, max. 19 and 20 (5)	Heavy dew at night.
10	0 to 1, die out	Fine, calm.
10	1 to 8, no tremors	—
11	No tremors	Calm, dull.
12	7 to 24, max. 22 (5)	Drizzle.
13	0 to 4, die out	Calm.
13	4 to 12, no tremors	—
13	12 to 21, slight	—
14	0 to 13, no tremors	Calm, fog.
14	13 to 23, max. 22 (5)	—
14	23 and 24, no tremors	Hoar frost in morning.
15	0 to 24, no tremors	Calm, dull. From noon high wind.
16	0 to 16, no tremors	High wind.
16	16 to 21, slight and slow	—
16	21 to 24, no tremors	—
17	0 to 24, no tremors	Calm, drizzle.
18	0 to 3, no tremors	Rain, N. wind.
18	3 to 24, max. 18 to 23 (5)	Decrease by opening door. Heavy dew and frost.
19	0 to 1, die out	Calm, fine.
19	1 to 8, no tremors	—
19	23, slight	—
20	0 to 24, no tremors	High wind, rain.
21	0 to 24, no tremors	Rain, S. wind.
22	0 to 17, no tremors	Dull, calm.
22	17 to 21, slight, slow	—
22	21 to 24, no tremors	—
23	0 to 16, no tremors	Calm, fog.
23	16 to 22, slow max. 18–19 (2 or 3)	—
23	22 to 24, no tremors	—
24	0 to 17, no tremors	Calm, fog.
24	18 to 21, slow max. 18 to 19	Record like 23rd.
25	No record except 20 to 24, when tremors are 2 mm.	Calm, dull.
26	0 to 5, die out	Rain, breeze, high wind.
26	5 to 14, no tremors	—
26	14 to 24, max. 19 (3)	—
27	0 to 4, die out	Fine, N.W. breeze.
27	4 to 10, no tremors	—
27	10 t 24 max. 17 to 19 (3)	—

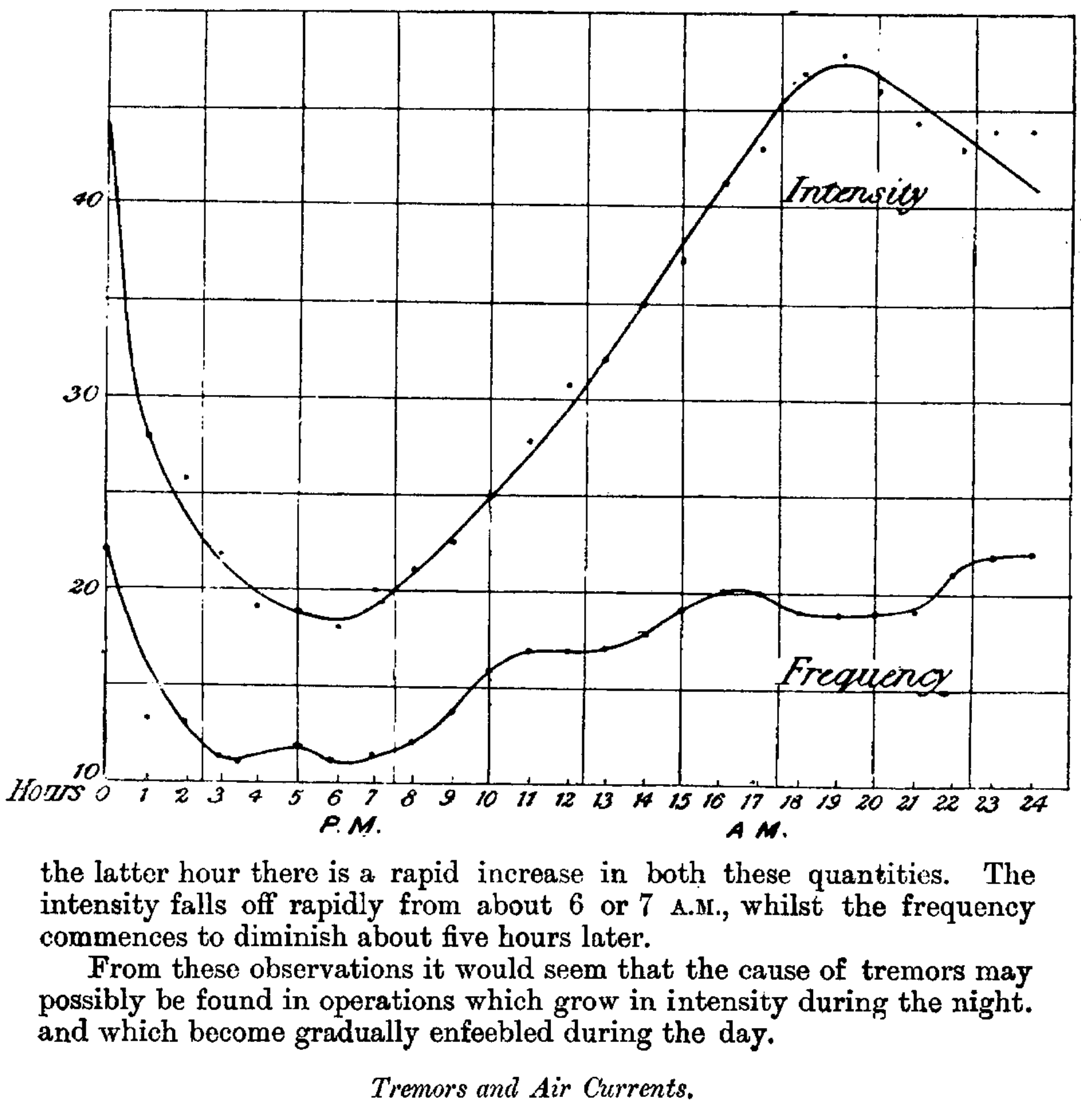
Relationship of Tremors to the Hours of Day and Night.

A general inspection of the preceding table leads to the conclusion that tremors have been more frequent and more intense during the night than during the day, and that they are especially marked during the early morning. To render this relationship more clear, tables have been made in which tremors for successive days have been placed under columns representing 24 hours, 12 hours being midnight. These tremors had values assigned to them equal in millimetres to the range of motion they exhibited on the photograms. By adding these columns up vertically a value was obtained for the period considered for each hour of the day and night. This value has been considered as proportional to the intensity of motion exhibited at various hours. By simply adding up the number of entries a set of numbers were obtained which may be regarded as proportional to the tremor frequency.

These two sets of numbers obtained for the months of November and December 1895, when plotted on squared paper, give the curves shown in fig. 8.

From these curves we see that for the period considered tremors have been least intense and least frequent between 3 P.M. and 7 P.M., but from

FIG. 8.—Tremors November and December 1895.



the latter hour there is a rapid increase in both these quantities. The intensity falls off rapidly from about 6 or 7 A.M., whilst the frequency commences to diminish about five hours later.

From these observations it would seem that the cause of tremors may possibly be found in operations which grow in intensity during the night. and which become gradually enfeebled during the day.

Tremors and Air Currents.

Inasmuch as the atmosphere may be calm, and the air inside an observatory may always be apparently quiescent, and yet an instrument not necessarily a horizontal pendulum, but an ordinary pendulum, a balance, and perhaps even a magnetometer, shows considerable motion within its case, the question arises whether there be not air currents existing within the cases which cover such instruments. With comparatively heavy horizontal pendulums in well ventilated cases in Japan tremors were always small and of rare occurrence, but with light pendulums in similar cases tremors of a pronounced character nearly always occurred between midnight and about six in the morning. With the *light* pendulum at Shide, beneath a fairly tight case, I found tremors, whether the inside of this was lined with thick felt, and the supporting pier covered with the same material, which kept the surroundings of the instrument at a fairly uniform temperature, or whether such coverings were removed. Covering those portions of the column which were inside the case with cement, and painting the surface of the same, did not destroy the intruders. Another experiment was to replace the large doors of the case with fine gauze, thus giving the instrument considerable ventilation ; but, as will be seen from the records (November 21–30), no great improvement was effected. By means of a very fine column of smoke from the spark at the end of a thin joss-stick, joints in the covering cases were tested for draughts. The column of smoke was also placed before a small hole usually closed by a cork, to see if there was any tendency in the air to enter or come out from the case, but no indication of the same was obtained.

One very marked observation was that a strong tremor storm would suddenly cease, or be at least greatly altered in its intensity, by opening the door of the case for one or two minutes.[1]

Although a sudden change of this last description has occurred without opening the doors, we have in this observation an indication that by some means or other, which do not seem to be effects due to differences in temperature in different parts of a case, air-currents are from time to time established within a case, the mechanical working of which can be more or less destroyed by simply opening the door of the case.

One cause of such currents may be due to the different rates at which aqueous vapour is absorbed or given off at different points within the covering, and if these are steady they may set up a steady set of long period displacements in a light pendulum.

By introducing a tray of calcium chloride inside the case, violent movements have resulted, which only ceased after the desiccating agent was removed.

These facts, coupled with the fact that tremors were apparently greatly reduced by surrounding the boom with a trough or wind-guard on three of its sides, lead to the conclusion that air-currents are from time to time generated within casings such as I have employed, which result in movements which are with difficulty separable from those which are attributed to motion of the supporting pier.

The fact that tremors occur when there is a slight fall in temperature outside the case, whilst the fall inside the same would be comparatively small, suggests the idea that at such times, although they have failed detection, there may be streams of air passing through the joints of the coverings. The unlikelihood of this is, however, referred to in the next section.

[1] In some instances, however, the opening of the door seems to have brought a tremor storm into existence.

Tremors in relation to Barometric Pressure, the Hygrometric State of the Atmosphere, Temperature, Frost, Dew, Wind, and Rain.

From November 18, 1895, a self-recording barometer, thermometer, and hygrometer of the Richard types were established at Shide. The two latter instruments usually stood upon the case covering the horizontal pendulum, but for one or two weeks they were placed inside the covering. The tremors have been written, with their magnitudes, on the diagrams showing changes in temperature. Although these changes, which are indicated in degrees Fahrenheit, have been within a period of twelve or twenty-four hours small, it must be remembered that the corresponding changes which have sometimes taken place outside the building may have been comparatively large. The following notes, in which T, B, and H respectively mean temperature, barometer, and hygrometer, are based upon an inspection of these records :—

1895.

Nov. 18–25 . . Tremors occur with falls of T, 55°–49°. B rising, 29·7–30·05 in., and H slightly fluctuating, 40·5–40·7.

Nov. 25–Dec. 2. Slight tremors, with falling T, which sometimes occurs during the day. B down to 29·4, and no tremors.

Dec. 2–9 . . . T falls 56°–40°, and strong tremors of 10 mm. B rising. H steady.

Dec. 16 . . . T at 48°, and tremors with falling T even during the day. B rising.

Dec. 16–23 . . T falls 48°–43°, and tremors. B rising.

Dec. 23–30 . . T falls to 43°, and tremors. B rising.

1896.

Jan. 6–13 . . T falls 50°–45°, but tremors are very slight. B very high.

Jan. 13–20 . . T falls 51°–45°, and heavy tremors of 10 mm.; but there are falls 50°–48° and no tremors. B 30·4. H steady.

Jan. 20–27 . . T 45° and fairly steady, with slight tremors, which, as usual, cease when it rises.

Jan. 27–Feb. 3. T falls 52°–43°, and heavy tremors. So long as it remains at 43° tremors are slight, but with the slightest fall, even to 42°, they recommence.

Feb. 3–10 . . T falls very slightly during the early morning on the 4th and 7th, and there are slight tremors. Whilst T is steady, even if it is low, there are no tremors; also no tremors when rising. B high. H fluctuates, but not at the time of the tremors.

Feb. 10–17 . . Slight tremors, with slight falls of T. B high. There are tremors with three falls of H.

Feb. 17–24 . . Tremors with three falls of T, commencing at 48°. A rapid fall of T on the 22nd was accompanied with heavy tremors. B high. H shows decided fluctuations, but at the times of no tremors.

Feb. 24–Mar. 2. T falls from 45°–40°, and tremors. B high. H has fluctuations, but these occur with or without tremors.

Mar. 2–9 . . . Tremors with T at 48°. A large B wave, 28·7–30·0, but no tremors. H fluctuating.

Mar. 9–16 . . T falls, 58°–53° and 53°–45°, and tremors. B high. H steady.

Mar. 16–23 . . T falls, 54°–52° and 54°–49°, and tremors. B moving steadily down and up, 29·5 to 30·0. H shows three waves, but not with tremors.

Mar. 23–30 . . Six cases of tremors with slight falls of T, and the lower T the greater the tremors. H very irregular. The tremors are most when the air is dryest. B shows several moderately rapid changes, and the tremors chiefly occur with the falls.

The conclusions which may be derived from these notes are :—

1. There does not appear to be any relationship between the indications of the hygrometer and tremors. When the door of the observing room was often left open during the day, at such times the hygrometer

would indicate considerable changes, which are the times at which tremors are least frequent.

2. Tremors have occurred when the barometer has been high, low, rising or falling. These observations, however, do not throw any light upon the connection which may exist between the appearance of tremors and the state of the barometric gradient.

3. Tremors nearly always appear when the temperature is falling, and therefore are frequent at night. When the temperature is steady or rising, tremors have been but seldom observed.

The observation that tremors accompany a falling thermometer receives strong confirmation that they have been markedly large on frosty nights, and that these sometimes have continued whilst the morning sun has been thawing the frozen surface of the ground. Such coincidences occurred on January 20, 28, 29, 30, 31, February 22, 23, 24, 25, March 14 and 18.

The only exceptions to this rule appear on November 25, January 14 and 15, on which occasions the fall in temperature was from 50° to 49° and 48°, which, it may be remarked, are only small changes.

From January 20 to 22 tremors were pronounced, whilst the temperature was steady at about 45°. Although there was this approximately constant temperature in the room, and a temperature yet more constant within the case, on the night of the 20th there was a hard frost, and possibly frost on the other nights. For each of these days it may therefore be assumed that between the day and night, outside the building, the change in temperature was great. The large differences in temperature between the outside and inside of the building no doubt resulted in the establishment of air-currents through a broken pane of glass and other air passages, but, as these do not appear to have disturbed the inside temperature, such air-currents must have been small. Rather, therefore, than looking to such currents as being the cause of the movements of the pendulum, it seems more reasonable to suppose them due to expansions and contractions which were taking place in the ground outside.

Tremors have also occurred on nights which have been accompanied with heavy dew, as, for example, on March 9. This may possibly mean that when large quantities of aqueous vapour are escaping from the ground, as evidenced by copious condensation on its chilled surface, contractions or expansions may be taking place in the same.

My note-book also shows, as it has repeatedly shown in previous years, that tremors have been marked or entirely absent with heavy winds from different directions and at the time of calms.

A long drought followed by heavy rain has been followed by slight tremors.

The conclusions that are arrived at respecting the cause of tremors are yet wanting in certitude.

It is probable that naturally produced elastic tremors with a high frequency have an existence in localities remote from earthquake centres, but this has not yet been demonstrated. The only records bearing upon such an investigation are a few taken at Shide. These are referred to when describing the Perry Tromometer.

The long-continued movements which are so often observed with *light* horizontal pendulums are probably due to the same causes which produce movements in ordinary pendulums, delicate balances, and, as the Rev. W. Sidgreaves tells us, in suspended magnets beneath *air-tight* covers at Kew and Stonyhurst.

As the result of many observations, I venture to suggest that the causes of the so-called 'earth tremors' are twofold :—

1. Air-currents within the cases. Such currents are produced by a cold current of air impinging upon the outside of covers like glass or thin metal, but they are not likely to be produced if the covering is made of thick wood lined with thick felt. They may be produced by an inflow or outflow of air through ill-fitting joints, but what is more likely, as experiment has shown, by a difference in the rate at which moisture is condensed, absorbed, or given off at different points within a cover.

2. By movements in the superficial soil outside the building in which the instrument is installed. These movements take place in soil whilst it is freezing or thawing, and after a heavy shower on dry ground. They may also be produced at the time when there are rapid but small changes in barometric pressure over an area the different portions of which vary in their elasticity and resilience.

Although these suggestions partially destroy the value of many records of 'earth' tremors, they nevertheless leave us confronted with phenomena which it is the interest of all who have to work with instruments having delicate suspensions to understand more clearly, especially, perhaps, the reason that their frequency is so marked at particular hours and seasons.

Diurnal Wave and Wandering of the Pendulum.

On May 24, 1896, a drum moving a bromide film at a rate of about 75 mm. in twenty-four hours was placed beneath pendulum T, and records were taken until June 15. The sensibility of the instrument was such that 1 mm. deflection indicated a tilt of 0″·56.

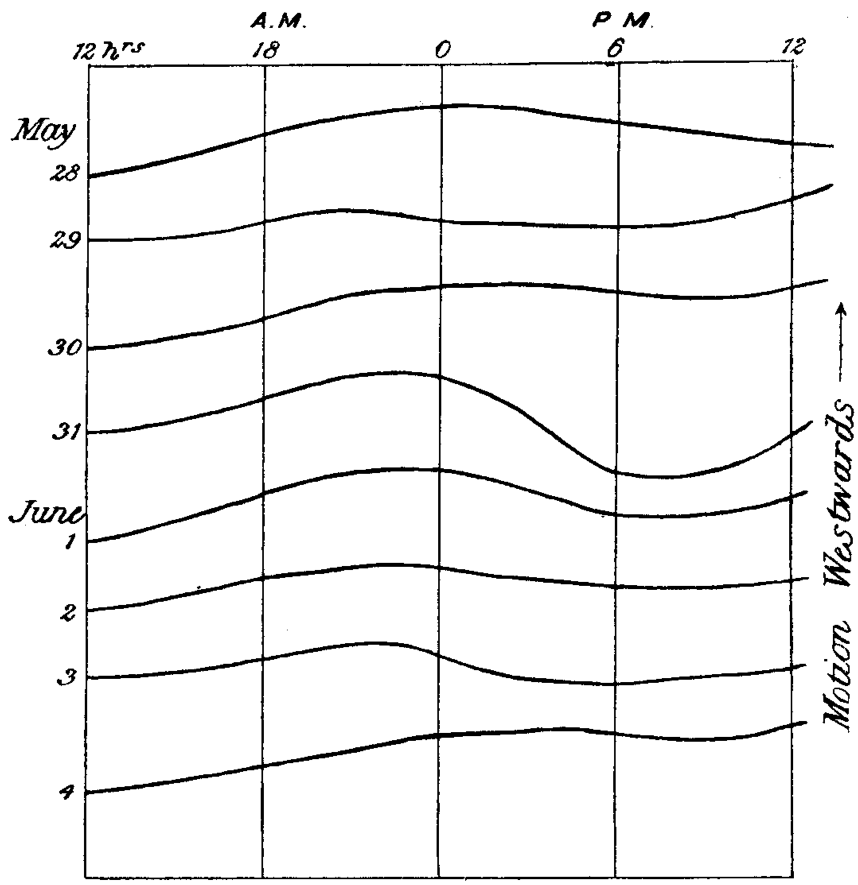
The records yield the following results :-

Date	Farthest East	Farthest West	Range of motion	Difference in Temperature	Remarks
	H.	H.	″	F	
May 24	8	18	1·12	5°	Rain last night
,, 25				5	Wave slight. Fine, cloudy, N. wind
,, 26				3	,, ,, Dull, S. wind
,, 27		24	1·12	7	Fine, E. wind
,, 28	8	24	3·92	6	Fine, N.W. wind
,, 29		3		7	Fair
	12	21	1·12		
,, 30	8	24	2·80	3	Dull, S.W. wind
,, 31	8	22	4·48	4	Fine, E. wind
June 1	8	22	3·36	8	Fine
,, 2		3		7	
	7	19–24	1·68		
,, 3	6	18–24	2·24	5	Fine
,, 4	6–7	24	1·68	6	Fine
,, 5	6–7	22	2·24	3	Dull, W. wind
,, 6	6–7	22		5	Wave slight. Fine rain, W. wind
,, 7		24		2	,, ,, Rain
,, 8				4	,, practically straight. Fine
,, 9				4	,, ,, ,, Dull, S. wind
,, 10				2	,, ,, ,, Drizzle
,, 11				3	,, ,, ,, ,,
,, 12		22		5	Fine
,, 13		22		7	Dull

The differences in temperature which are in degrees Fahrenheit are those recorded in the instrument room between about 8 A.M. and 2 P.M.

Fig. 9 shows tracings from the photograms of diurnal waves observed at Shide. The range of motion has varied between 1″ and 5″. Usually the Western motion ceased about 10 A.M., from which hour the pendulum moved eastwards until about 7 or 8 P.M. The motion from 10 A.M. or noon is therefore similar to that which would accompany a decrease in the steepness of the open bare down on the eastern side of the pendulum, or a rising of the tree and grass covered valley on its western side. The fact that the movements were usually pronounced on bright fine days, and but

FIG. 9.—Diurnal Wave at Shide.



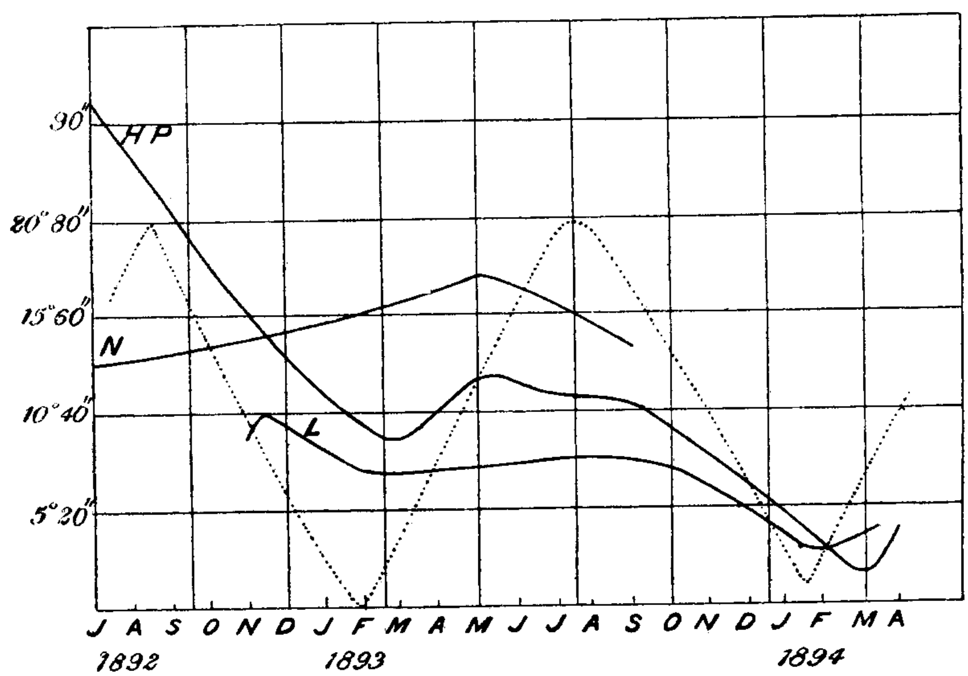
feeble or absent when it was dull or wet, suggests the idea that the observed movements may have been the result of the removal by evaporation of different loads from the two sides of the station. The amplitude of the daily wave is far from being proportional to the daily range of temperature observed near to the instrument.

From May 24 to June 7 the pendulum gradually moved westwards, and during this time the maximum temperature gradually rose from 60° to 70°, that is to say, the direction of motion has been the same as that which takes place whilst the temperature is rising during the day. The creeping of the pendulum between the above two dates is in such a direction that it might be attributed to the removal of a larger load from the hill side of the instrument than from the valley side.

Between June 6 and 7 the maximum temperature fell to 65°, from which it rose to 68° on the 11th. During this time, however, the pendulum crept eastwards, or in the opposite direction to that in which, under similar conditions, it had been previously moving. From June 11 to 13 the temperature rose from 65° to 72°, whilst the pendulum remained stationary.

What these observations show for a period of only twenty-one days is true for longer periods, as observed in Japan, and generally agrees with the observations made at Strassburg, described by the late Dr. E. von Rebeur-Paschwitz. At this latter place, for a period of nineteen months, the character of the curve of wandering is similar to that for a curve of temperature; but when we observe, as this author points out, that the minimum of temperature is reached from $1\frac{1}{2}$ to 2 months *before* a minimum in the curve, showing the displacement in the pendulum, whilst its maximum is reached about four months *later*, the relationship between the two becomes obscured. This and other results obtained at Strassburg are shown in fig. 10, reduced from the observations of von Rebeur.

Fig. 10.



In this diagram the temperature curve taken in the cellar where the pendulum was installed is shown in dots. H P is the horizontal pendulum curve, L a curve from level observations, and N a Nadir curve. An increase in reading indicates a movement towards the north. Although, these three sets of observations were made with instruments near to each other, the difference of the Nadir curve from the other two is very striking. The amounts of change are also noticeable, the horizontal pendulum having been tilted towards the south through 87″, and if we take it from the commencement of the observations in April, 1892, this is increased to 143″.

III. *Changes in the Vertical observed in Tokio, September* 19, 1894, *to March* 1, 1896.

Pendulum L.—On September 19, 1894, pendulum L, which has a boom about 5 feet in length, was installed beneath a wooden case on the concrete floor of a cellar in the N.W. corner of the College of Engineering at the Imperial University of Japan, in Tokio. When set up it had a period of about twenty-eight seconds, and 1 mm. deflection at the end of the boom which is in the meridian corresponds to an angular tilt of about $0''{\cdot}5$. The doubt expressed regarding the value of the readings of this instrument arises from the fact that the notes relating to its calibration were lost by fire. When the readings increase in value the pendulum is swinging towards the west, which means that the ground may have been raised upon its eastern side. The diurnal motions of this instrument were small, not exceeding 1 or 2 mm. For several days readings taken about 9 A.M. have been identical, after which there would be noted a displacement of 1 or more mm. For the first nine months these apparently sudden displacements were towards the east. This was followed by three months of westerly motion, and then three months more of displacements towards the east. For the remaining three months, although the general direction of motion is westwards, it has been somewhat erratic in character.

The readings given in the following table are in millimetres, and the date for any reading is the day on which there was a change from the reading which precedes it.

Date	Deflection	Date	Deflection
1894, September . .	100 to 101	1895, August 1 . .	79
October 1 . .	95	„ 7 . .	80
„ 9 . .	96	„ 11 . .	81
„ 18 . .	95	„ 23 . .	82
„ 24 . .	96	September 8 .	81
„ 31 . .	95	„ 10 .	80
November 24 .	102	„ 15 .	79
„ 27 .	100	„ 25 .	75
„ 30 .	97	October 14 . .	73
December 3 .	95	„ 17 . .	74
„ 20 .	97	„ 19 . .	70
1895, January 20 . .	89	„ 20 . .	66
February 18 .	88	„ 23 . .	64
March 10 . .	86	„ 26 . .	63
„ 25 . .	85	November 1 .	60
April 3 . .	84	„ 24 .	59
„ 30 . .	83	December 8 .	64
May 6 . . .	76	„ 16 .	63
„ 8 . . .	75	„ 24 .	64
June 11 . .	68	1896, January 10 . .	61
„ 19 . .	69	„ 19 . .	60
July 5 . .	70	„ 27 . .	71
„ 10 . .	73	February 9 .	67
„ 14 . .	74	„ 13 .	69
„ 18 . .	76	„ 16 .	70
„ 27 . .	78	„ 23 .	68
		„ 29 . .	66

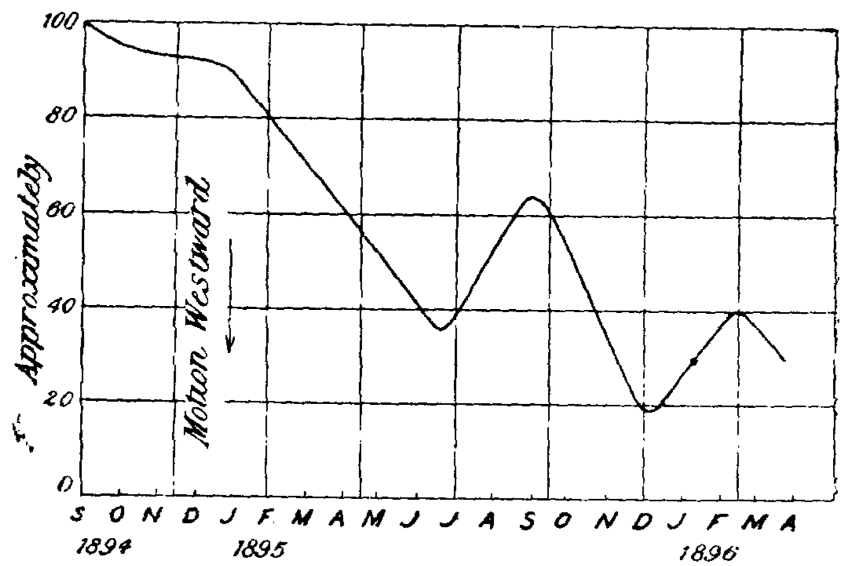
A fact of some importance connected with these displacements is that very many of them took place at the time of earthquakes which were sensible, and most of these small jumps were in the general direction in which the pendulum was suffering displacement. My late colleague, Mr. C. D. West, who from time to time has sent me these readings which are taken by one of the college servants, tells me that the displacement of January 26–27, 1896, cannot be accounted for, but the readings generally follow the seasonal changes in temperature—a conclusion which is at least true for 1895. *Fig.* 11.

With the assumed values for the readings the approximate changes in the vertical have been as follows :—

	"		
September, 1894, to June 11, 1895	16·0	East side	sinking
June 11, 1895, to August 23, 1895	7·0	"	rising
August 23, 1895, to November 24, 1895	11·0	"	sinking
November 24, 1895, to January 27, 1896	6·0	"	rising
January 27, 1896, to February 29, 1896	2·5	"	sinking
Total change during whole period	17·0	"	sinking

This long-continued creeping in one direction is common to observations made by Plantamour and others who have made like investigations.

FIG. 11.—Change in Level observed in Tokio.



IV. *Experiments with a Horizontal Pendulum at the Oxford University Observatory,* 1896, *May* 5. *Drawn up by* Professor H. H. TURNER.

1. During the morning Professor Milne set up his horizontal pendulum, which is similar to the one at Shide, on the slate slab in the Students' Observatory. The level of the transit circle was set up on the same slab near the H.P., and watched throughout by Captain E. H. Hills, R.E. This slab rested on a hollow foundation of bricks about 10 inches in height, which in turn rested upon a bed of concrete a few inches in thickness, and common to the whole building. Beneath the concrete there is a natural bed of gravel a few inches in thickness. Because the horizontal pendulum, which pointed from E. to W., stood on the slab near to its edge, it was to be expected that a load on the south side at a distance of, say, 3 feet would produce a greater effect than the same load would produce when moved to the north side, where it would be distant 7 or 8 feet.

The value of one division of the level may be taken $=1''{\cdot}0$.

The changes of level N. and S. were observed.

2. The crowd collected at 12.15–12.20: 76 men in all. Four companies of 18 each (with commanders=19) were formed by Mr. G. C. Bourne. These were halted with front rank 90 feet from observatory. (Pos. I.)

Then marched up, two rear companies taken over fence and brought up inside: front rank 5 feet from N. side of building=10 feet from slab. (Pos. II.)

Then retired to 90 feet. (Pos. III.)

Then marched up again 'closer'; the two front companies came close up to building; front rank thus about 5 feet from slab: other ranks say 7, 9, and 11 feet from slab. (Pos. IV.)

Then away again. (Pos. V.)

Then marched up *in open order*, viz.: Each man two arm's lengths away: say at 5 feet apart. Front rank still close to hut, *i.e.* 5 feet from slab; 2nd rank, 10 feet; 3rd, 15 feet; 4th, 20, &c., to 8th, at 40 feet from slab. (Pos. VI.)

Then away again. (Pos. VII.)

Then in more open order, say 10 feet apart: } (Pos. VIII.)

Front rank 10 feet away: . . . .
2nd „ 20 „ . . . . .
3rd „ 30 „ . . . . .
8th „ 80 „ . . . . .

Then away. (Pos. IX.)

Then *on the south side*: In close order, front rank 5 feet away, next $6\frac{1}{2}$ say, &c. (Pos. X.)

Then away=Pos. XI.

A few experiments were made inside the observatory with loads of one or three men standing on the board floor within 3 or 7 feet of the instruments.

The results obtained were as follows:—

Result of Loads outside the Observatory.

Time	Position	Approximate Distance from Slab: Front Rank	Approximate Distance from Slab: Rear Rank	Order	Side N. or S.	Horizontal Pendulum	Level (Mean of 2 ends)	Taking the difference between any reading and the readings before and after mean: Effect H.P.	Effect Level	Mean of 2
		FT.	FT.				″	″	″	″
12.20	O.	—	—	—	—	—	15·20			
12.25	O.	—	—	—	—	49·5	15·60			
12.27 to 12.28	I.	90	102	close	N.	49·5	16·00			
12.29 to 12.31	II.	10	22	„	N.	50·5	15·70	+1·25=+0·42	+0·25	+0·34
12.32 to 12.34	III.	90	102	„	N.	49·0	15·90			
12.35 to 12.37	IV.	5	22	„	N.	50·0	15·10	+1·50=+0·50	+0·73	+0·62
12.38 to 12.40	V.	90	102	„	N.	48·0	15·75			
12.41 to 12.43	VI.	5	40	open	N.	48·0 afterwards	15·35	0·00=0·00	+0·32	+0·16
12.44 to 12.46	VII.	90	102	„	N.	47·0	15·60			
12.47 to 12.48	VIII.	10	80	very open	N.	47·0	15·15	+0·50=0·17	0·00	+0·08
12.49 to 12.50	IX.	90	102	„	N. & S.	46·0 afterwards 45·25	14·50			
12.54 to 12.55	X.	5	15	close	S.	44·25	15·65	−1·13=−0·38	−0·65	−0·52
12.56 to 12.57	XI.	90	102	„	S.	45·5	15·50			

For load approaching on N. side readings of H.P. increase.—Level decrease.
„ „ S. „ „ decrease.—Level increase.
One division of the horizontal pendulum $=0''{\cdot}33$.

3. Experiments *inside* the hut, within 3 feet S. side and 7 feet N. side of the instrument.

Effect of 240 lb. Zero 59.

On North side, Reading	60·5.	Effect	1·5 = 0″·49
„ South „ „	54·5.	„	4·5 = 1″·48
„ North „ „	60·5.	„	1·5 = 0″·49

Effect of 570 lb. Zero 59.

On South side, Reading	50.	Effect	9 = 2″·97
„ North „ „	66.	„	7 = 2″·31

4. Experiment with load outside the hut within 5 feet on S. side and 5 feet on N. side.

Effect of 570 lb. Zero 56.

On South side, Reading	55.	Effect	1 = 0″·33
„ North „ „	55.	„	0 = 0

This last reading is unsatisfactory. Five minutes later it became 55·5, but if the north side load showed an effect it ought to have exceeded 56.

In the afternoon a few experiments were made in the main building of the Observatory. The horizontal pendulum was placed on the top of a massive pier whilst two boys and a man (almost 350 lb.) stationed themselves in the basement of the building, first on the east side and then on the west side of the same. The difference in readings given by the two positions was approximately 0″·16.

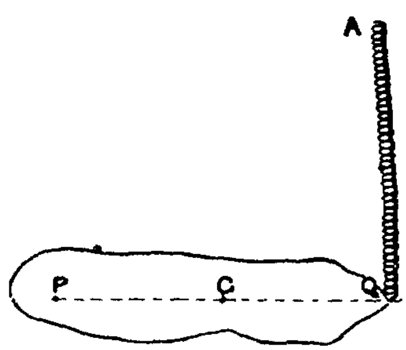
V. *The Perry Tromometer. By* Professor JOHN PERRY, *F.R.S.*

What is interesting about the apparatus is this, that any periodic motion of the supports is faithfully indicated by the pointer if its frequency is several times the natural frequency of vibration when its supports are at rest.

One body supported on a pivot with three Ayrton-Perry springs will record the vertical and two horizontal motions.

A body P G Q is free to move about an axis P at right angles to the paper. G is its centre of gravity. An Ayrton-Perry spring is applied

FIG. 12.



vertically at Q from the point A. Weight of body is W. Vertical force at P is P, force at Q is Q. Let P and A get a vertical displacement x_1 downward, and let Q be displaced x downward. Let $Q=Q_0+c(x-x_1)$ where c represents the constant of the spring. Then forming the equations of motion we find, neglecting friction

$$x+n^2x=ex_1+n^2x_1 \quad . \quad . \quad . \quad . \quad (1)$$

Where $\frac{c(a+b)^2}{M(k^2+a^2)}$ is called n^2 so that n divided by 2π is the frequency of the natural vibration of Q.

$$\frac{k^2-ab}{k^2+a^2} \text{ is called } e.$$

The distance PG is called a, and GQ is b, M is the mass of the body and k its radius of gyration about G.

Assuming that friction will destroy the natural vibrations at Q, but neglecting the easily expressed friction term of (1), the forced vibration is easy to find. If an observer moves with P and A, he observes, not x, but $x-x_1$. Let $y=x-x_1$. Then if $x_1=h \sin qt$,

$$y=-h\frac{a(a+b)}{k^2+a^2}\frac{q^2}{q^2-n^2}\sin qt.$$

Now if we arrange that n is, say, less than one-fifth of q [that is, that the natural frequency of Q is less than one-fifth of the frequency of A and P] we may say that the motion y which is observed is a faithful imitation of any periodic motion of P and A; or, letting $a+b$ or PQ be called l and $k^2+a^2=k_1^2$, the square of the radius of gyration about P, $y=-\frac{al}{k_1^2}x_1$.

A magnifying pointer on the spring enables this motion to be observed.

It is obvious that the motion may be in a horizontal plane instead of a vertical.

Note. By Professor JOHN MILNE.

A form of Perry Tromometer as experimented with at Shide consists of a horizontal beam free to oscillate upon a knife edge. This beam is heavily loaded by two unequal masses which to obtain a balance are placed at different distances from the knife edge. Attached to one of these masses and running vertically upwards is a light A.P. spring, the top end of which is held by a fixed support. To show the movements of the spring which coils or uncoils with vertical vibratory motion, a very light pointer, or a small mirror from which a beam of light is reflected, is attached to the same. One photogram representing a period of twenty-four hours has been obtained by this instrument at Shide. This shows that during nearly the whole of the day the mirror is in motion, and the fact that this motion is due to passing carts, carriages at a distance of several hundred yards, and trains at a distance of about a mile speedily led to the conclusion that an instrument so extremely sensitive to rapid elastic motion could not be used at Shide. One interesting observation was that, at the time of the funeral of Prince Henry of Battenberg, when minute guns were being fired on ship-board at a distance of about five miles, each sound wave was accompanied by the sudden displacement of the spot of light through a distance of about one foot. It did not seem that vibrations came from their origin through the ground to disturb the instrument, but as sound waves through the air, which shook the building and the foundation on which the instrument rested.

If an instrument of this description could be installed at a locality where we can assure ourselves that its movements could only be due to natural causes, it seems likely that we should add to our records of the movements of the earth's crust forms of vibration which horizontal pendulums and seismographs are incapable of recording.

VI. *Earthquake Frequency.* (*Extract from a letter written by* Dr. C. G. Knott.)

In my paper on Earthquake Frequency ('Trans. Seis. Soc. Japan,' vol. ix. 1884), in which, probably for the first time, a sound mathematical treatment of periodicity was insisted upon, various possible causes of periodicity in earthquake frequency were considered. Next to the solar annual and diurnal periods, the most important are the lunar monthly, fortnightly, and daily periods. From lack of completeness of information at that time, it was impossible to search for these. But the great eight years' list of 8,331 Japanese earthquakes, prepared recently by Professor Milne, seemed eminently suitable for harmonic treatment. Other necessary work has prevented me getting the investigation carried out so quickly as I had wished, but enough has been done to show the probable results in certain directions.

The idea is that the tidal stresses due to the moon influence the periodicity. The lunar day gives a periodic tidal stress of comparatively short period; the *anomalistic* month (from apogee to apogee) and the *nodical* month (from ascending node to ascending node), give periodic tidal stresses of long period.

Tabulating the earthquakes according to the number of days each has happened after apogee, or after ascending node, we get two statistical tables of monthly means, one nearly 100 months. The anomalistic month is longer than the nodical month by almost exactly one-third of a day—in the hundred months, therefore, one will have gained upon the other by thirty days, or fully one month. The curves obtained, when created by harmonic analysis, give monthly, fortnightly, and weekly periods; but the fortnightly is more marked in the nodical curve than in the anomalistic.

In discussing the daily lunar period, we must take account of the *districts* in which the earthquakes occur, for only in this way can we compare their times of occurrence with the time of meridian passage, or the time of high water. In the case of the Tokio and Yokohama district, there is evidence of a half daily period; but the investigation is still far from complete.

VII. *Instruments used in Italy.* *By* Dr. C. Davison.

In the following pages a description is given of a few of the principal instruments used in Italy for the registration of pulsations proceeding from more or less distant origins.

Many of the instruments erected in that country are long vertical pendulums, the movements of which are magnified and registered in different ways. The length is made as great as circumstances will allow, so that for rapid vibrations the bob may be practically a steady point, and the bob is made as heavy as possible, so as to lessen the friction introduced by the mechanical registration. Those who have used these pendulums claim that they possess the following advantages over the horizontal pendulum and other instruments designed for photographic registration.

1. They are much less expensive to work; the cost of the paper on

which the records are made being only about a franc or a franc and a half a month.

2. Any person can superintend and adjust them easily.

3. They are not subject to the displacement of the zero-line.

4. Owing to the great velocity which can be given to the paper, the epoch of the different phases of the movement can be determined with great accuracy.

5. They allow all the minute details of the movement to be studied.

It is obvious that these, especially the two last, are great advantages. On the other hand, the long pendulums are subject to several objections as compared with the horizontal and bifilar pendulums.

1. Owing to their great length (Professor Riccò's seismometrograph at Catania is 26 metres long), they are difficult to install, and indeed require a building almost specially constructed for the purpose.

2. They are much less delicate than the horizontal and bifilar pendulums.

3. The latter are also adapted for other purposes *e.g.*, investigating the bending of the ground by barometric and tidal loading—and this will facilitate their adoption at astronomical observatories, where, from the ease with which the exact time can be ascertained, it is most desirable that they should be established.

The instruments I propose to describe are: (1) Professor G. Vicentini's microseismograph; (2) Dr. G. Agamennone's seismometrograph, (3) Dr. A. Cancani's seismometrograph, and (4) Professor G. Grablovitz's geodynamic levels. It will be seen that the first of these is more or less free from the above-named objections.

Professor G. Vicentini's Microseismograph.—An account of this instrument and the results which have so far been obtained with it is given in the following papers:

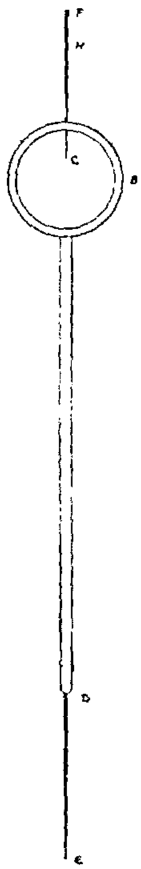
1. G. Vicentini: Osservazioni e proposte sullo studio dei movimenti microsismici: 'Atti della R. Accad. dei Fisiocritici' (Siena), vol. v. 1894.
2. G. Vicentini: Osservazioni sismiche (two papers): *Ibid.*
3. G. Vicentini: Movimenti sismici registrati dal microsismografo nella prima metà del luglio 1894: *Ibid.*
4. M. Cinelli: Sulle registrazioni del microsismografo Vicentini avute a Siena del 15 luglio al 31 ottobre 1894: *Ibid.*
5. G. Vicentini: Microsismografo a registrazione continua: Cenno sui movimenti sismici dei giorni 14 e 15 aprile 1895: 'Bull. della Soc. Veneto-Trentina di Scienze Naturali' (Padova), vol. vi. 1895, pp. 5–12.
6. G. Vicentini: Microsismografo a registrazione continua: 'Boll. della Soc. Sismol. Ital.,' vol. i. 1895, pp. 66–72.
7. G. Vicentini: Intorno ad alcuni fatti risultanti da osservazioni microsismiche: 'Atti e Mem. della R. Accad di Scienze, &c., in Padova,' vol. xii. 1896, pp. 89–97.
8. G. Vicentini and G. Pacher: Considerazioni sugli apparecchi sismici registratori e modificazione del microsismografo a due componenti: 'Atti del R. Ist. Veneto di Scienze,' &c., vol. vii. 1896, pp. 385–399.
9. G. Vicentini: Fenomeni sismici osservati a Padova dal febbraio al settembre 1895 col microsismografo a due componenti: 'Atti della Soc. Veneto-Trentina di Scienze Naturali' (Padova), vol. iii. 1896, pp. 3–63.

Some further details with regard to the construction of the instrument are taken from two letters written by Professor Vicentini to Professor Milne.

Professor Vicentini was led to design this instrument owing, he says, to the difficulty of obtaining good photographic registration, the inconvenience of working in the dark, and of using an apparatus which does not give its record until the sensitive paper is developed, and to the great expense of the photographic paper, the chemical reagents, and the source of light.

His first experiments were made with an ordinary tromometer, about 1·50 metre long, and with a bob 50 kg. in weight. The support of the pendulum was fixed in a wall of the University buildings of Siena, overlooking a much frequented road, on the third floor, and about 20 metres above the ground. A short straw, terminating in a fine steel wire, was attached to the bottom of the bob, and the movements of the point of the wire were observed by means of a totally-reflecting prism and microscope provided with a micrometer. A tromometer of this kind does not give at any instant the true state of vibration of the ground, its movements being affected by previous disturbances. But if the pendulum be obliged to perform a very little work, such as the movement of the light vertical lever described below (fig. 13), the bob is rendered much more insensible to the rapid vibrations of the point of suspension. Substituting this lever for the straw referred to above, the movements of the lower end were observed with the microscope. The superiority of this arrangement is very evident. When a carriage, for instance, approaches from a distance, the point of the lever at first vibrates parallel to the wall, then in a plane more and more inclined to it, until, when the carriage is just opposite the building, the vibrations are performed normally to the wall and are synchronous with the trampling of the horses. When the vibration of the ground ceases, the movement of the lever ceases contemporaneously. Thus, by the application of this vertical lever, the bob of the pendulum is transformed almost into a steady mass, and its steadiness during movements of the ground is further promoted by the addition of the two horizontal levers which give the component movements in two directions at right angles to one another.

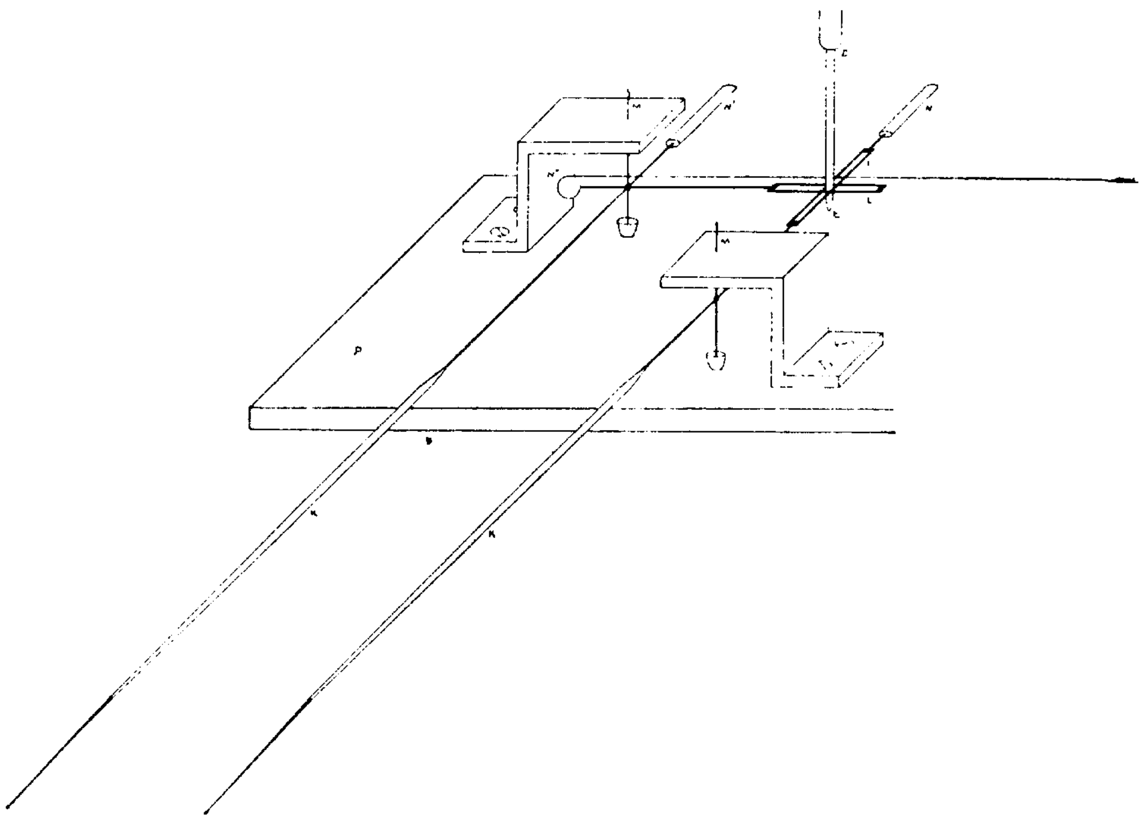
FIG. 13.



In the complete microseismograph erected in the University of Siena, the bob of the pendulum weighs 50 kg., and is supported by three chains, united at their upper ends in a brass cap, to which is attached an iron wire about 2 mm. in diameter. This is fastened to a screw in a strong iron bracket driven into the wall. The length of the pendulum is about 1·50 metre. By means of the screw the bob can be raised or lowered. Immediately below the latter are fixed two iron bars to support it, and prevent damage to the registering apparatus in case the suspending wire or chains should break. The bob is also surrounded by an iron ring carrying three screws, whose office is to prevent excessive displacements of the pendulum. When the pendulum is connected with the recording levers it performs complete oscillations in 2·4 seconds.

Fig. 13 shows the vertical amplifying lever referred to above. It consists of a thin tube of aluminium A, soldered at its upper end to a ring B of the same metal. To its lower end is fixed a sewing-needle, DE, whose cylindrical part has a diameter of 0·6 mm. The ring B is traversed at its highest point by a second needle, FG, exactly similar to the first. Its point, G, penetrating a short way inside the ring, rests in a small glass cup carried by a support fixed to the wall. The position of the cup can be adjusted by screws, both horizontally and vertically. The base of the bob is slightly conical, and in its centre a hole is made, covered by a sheet of brass, in which a small hole with bevelled edges is made which clasps the needle, FG, at the point H. By means of the adjusting screws fitted to the glass cup, the points G and E of the needles are placed as nearly as possible in a vertical line below the centre of gravity of the bob. So long as the bob remains steady the point H is the fulcrum of the lever, and the movements of the wall are magnified at the end E in the ratio

FIG. 14.



EH to GH. The total weight of this lever is 2·2 grammes ; its length is 144 mm., and the ratio EH to GH is equal to 16. The friction at both the points G and H is extremely small.

The movements of the lower end of the vertical lever are magnified by two light horizontal levers (fig. 14), which give the components of its motion in directions at right angles to one another. It should be mentioned that this figure is not drawn exactly to scale, and illustrates the slightly different arrangement in a new microseismograph recently erected at Padua.

One of the levers, K, is rectilinear, and the other, K′, bent at right angles. In the Siena instrument they are made of thin aluminium plate, terminating, at the ends L and L′, in two very thin burnished steel needles, parallel to one another, and separated by a distance equal to the thickness of the needle, DE, of the vertical lever. The vertical axis, M, consists of a fine steel needle, the lower point of which rests in the conical cavity of a small glass cup fixed to the plate, P. The axis, M′, is exactly similar, but the lower end rests in a glass cup, whose height above the plate, P, can be adjusted by a screw. The levers are provided with counterpoises, N, N′, N″. The needle, DE, of the vertical lever passes through the slits, L, L′, and thus any displacement of the end, E, is decomposed by the horizontal levers into two components at right angles to one another.

At the free ends of the aluminium arms of the levers, fibres of glass are fixed at right angles to them with melted wax. In the apparatus afterwards erected at Padua (to which fig. 14 refers), these glass fibres are replaced by broad but thin strips of glass, the terminal parts being drawn out as fibres.

In the horizontal levers the length of the long arm is about five times that of the short arm; the movements of the wall supporting the apparatus are therefore magnified about eighty times.

The smoked paper on which the records are made is a continuous strip, and is driven by a drum which revolves by clockwork. The drum is placed so that the pens rest on its highest horizontal generator, and the fibres are made of such thickness and length that, with the slight friction to be overcome, they do not bend. To diminish their friction they are fused at the tip; the smooth surface of a very small sphere of glass thus slides on the smoked paper. To equalise the friction of the two pens, that of the pen K is first regulated by raising or lowering the support on which the plate P rests by means of the levelling screws with which it is provided. The contact of the other pen is then adjusted by moving the glass cup on which the axis M′ rests. The clock which drives the drum may be of any kind, but, in order to measure the time, a chronograph is connected with a good pendulum clock which closes an electric circuit, and thus causes a stroke to be made on the paper every minute. At each hour a double mark is made.

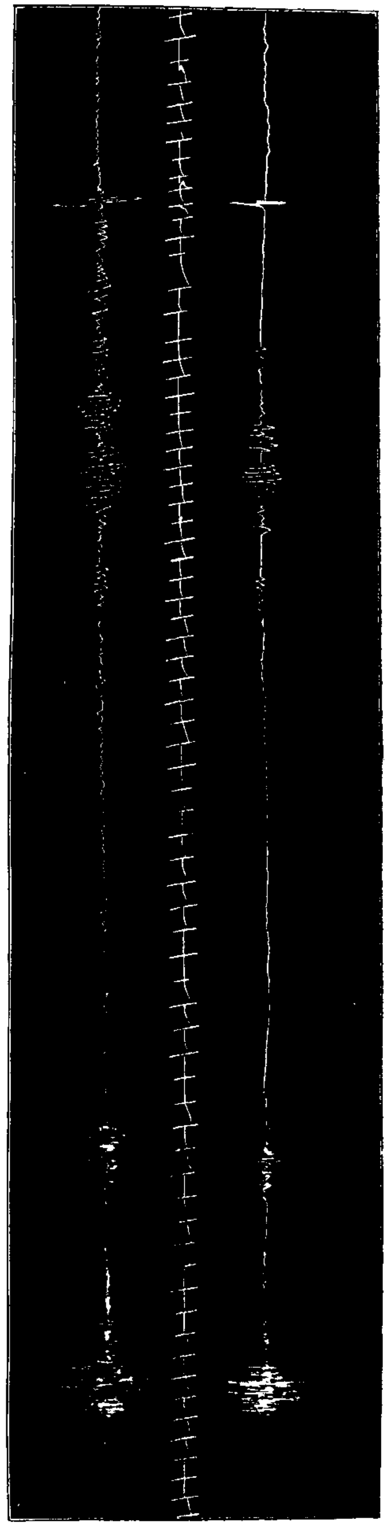
The strip of paper is unrolled at the rate of about 2 mm. a minute. The pens leave on the paper a fine but very clear trace. When heavy carts pass by the University buildings the lines are simply widened, the lampblack being completely carried away. In the case of earthquake movements, however, the separate oscillations are clearly perceptible, though the more rapid ones are only to be seen with the aid of a lens. Fig. 15 reproduces the diagram obtained at Siena of the Japanese earthquake of March 22, 1894. The toothed line in the middle shows the strokes which mark consecutive minutes. This figure may be compared with the record of the same earthquake obtained by means of the horizontal pendulum at Nicolaiew.[1]

Beside the microseismograph above described, Professor Vicentini has recently erected a new instrument at Padua, designed, not for obtaining the times of the different phases of a disturbance, but for determining with greater exactness the direction in which the movement takes place. The mass of the new pendulum is 100 kg., and its length 3·36 metres. It contains a vertical amplifying lever, like the first instrument, but for the horizontal levers a small pantagraph was substituted at Dr. Pacher's suggestion. This is made of aluminium tubes, weighs about eight deci-

[1] See *Brit. Assoc. Rep.*, 1894, p. 156.

grammes, and magnifies five times the displacements of the lower end of the vertical lever. The rate of the smoked paper is increased to about 15 mm. a minute, a velocity which enables the pendular oscillations to be distinctly traced.

FIG. 15.



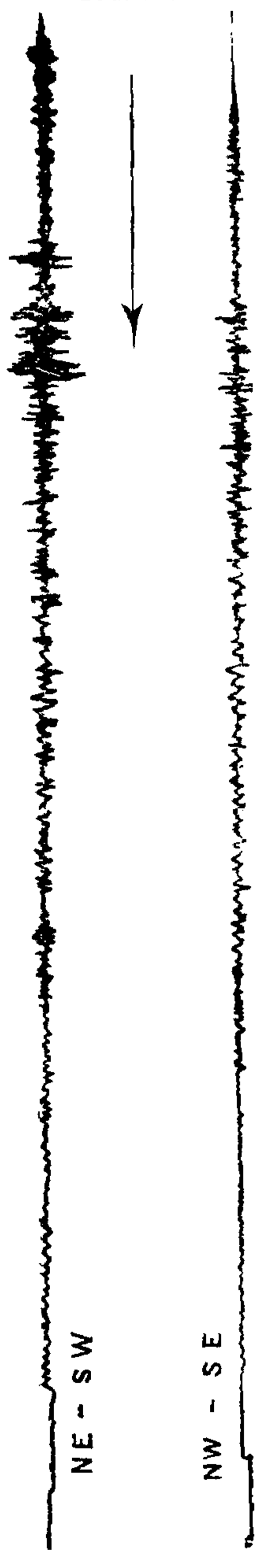
Dr. G. Agamennone's Seismometrograph.—The latest form of this instrument is described in a paper, 'Sopra un nuovo tipo di sismometrografo' ('Boll. Soc. Sismol. Ital.,' vol. i. 1895, pp. 160–168). It was installed at Rome about two years ago in the tower of the Collegio Romano. Owing to the difficulty of reproducing the illustration of this pendulum, several of the details of construction are necessarily omitted in the following account:—

The bob of the pendulum consists of six discs of lead, weighing altogether nearly 200 kg. This heavy mass is suspended by an iron rod 7 or 8 mm. in diameter and 16 metres in length, but to make the pendulum more sensitive the upper end of the rod is prolonged as a steel wire 2 or 3 mm. in diameter, and 50 or 60 cm. long. At the lower end the rod terminates in a smooth cylinder of steel of about the same thickness, passing through slits made in the short arms of two horizontal levers. These levers, which turn with very little friction, are mounted on a strong frame provided with screws for securing the verticality of the axes about which the levers rotate. The longer arms of the levers are about 35 cm. in length, being about twelve times as long as the short arms. They are triangular in form, and are made of very thin brass tubes. The levers are bent, so that while the short arms are at right angles to one another, pens at the ends of the long arms record the components of the movement on the same strip of moving paper. The pens are supplied with ink of different colours to avoid confusion of the records if the pens should happen to cross one another. In order to prevent the pens leaving the strip of paper, the movements of the pendulum are limited by four screws. A strong box is placed immediately below the heavy mass to save the instrument from further damage in case the steel wire should break.

The strip of paper on which the pens record the movements of the pendulum is driven by a cylinder about

8 cm. in diameter, and rotating about a horizontal axis. The part of the paper on which the record is being made lies on a rectangular platform immediately above the driving cylinder. Two pens fixed to the platform record the time every half-hour on the edges of the strip of paper. As a rule the cylinder rotates once in an hour, so that the paper is driven at the rate of about 30 cm. an hour. But when a shock occurs the velocity of the cylinder is immediately increased, so that for three revolutions it revolves once a minute, thus unrolling the paper at the rate of about 5 cm. a minute.

FIG. 16.



The increased velocity is produced by means of a roller, started by an electrical seismoscope. This consists in the longer arms of the levers being continued backwards to a length about fifteen times as great as that of the short arms. Beside, and very near the further ends, are two small vertical rods, which turn at their lower ends about a horizontal axis. A very slight movement of the levers closes an electric circuit, and at the same instant sets in motion the roller which gives the increased velocity, moves a collar which at once withdraws the vertical rods, so that they do not impede the oscillations of the multiplying levers, and also starts a clock previously pointing to xii. The latter clock thus gives the time at which the increased velocity began.

The increased velocity continues, as already mentioned, for three minutes. At the end of this time the two vertical rods return to their original position. But if the pendulum is still in motion, electrical contact is immediately remade, the rods are again withdrawn, and the increased velocity re-established, so that with instantaneous interruptions this lasts until the movement is so slight that it ceases to start the seismoscope.

Fig. 16 reproduces a diagram furnished by this seismometrograph on the occasion of the Caspian Sea earthquake of July 8, 1895.

Dr. A. Cancani's Seismometrograph.—The chief difference in principle between this instrument and the preceding consists in the omission of the arrangements for increasing the velocity at the time of a disturbance. Seismometrographs of this pattern have been in use for some time in the the geodynamic observatory of Rocca di Papa near Rome. Two apparatus of larger dimensions have recently been constructed, one for Rocca di Papa and the other for the observatory at Catania. These are described in a paper, 'Nuovo modello di sismometrografo a registrazione continua' ('Boll. Soc. Sismol. Ital.,' vol. ii. 1896, pp. 62-65).

In the Rocca di Papa seismometrograph, the pendulum is 15 metres long and 200 kg. in mass. The weight is suspended by a steel wire

4·5 mm. in diameter. Near its lower end, the wire passes through slits in the short arms of two horizontal levers. The long arms of the levers are made of two very light brass tubes which, soldered to a small metal plate, form a very elongated isosceles triangle in a horizontal plane. The short arms are inclined at 45° to the long arms in opposite directions, so that, while the former are at right angles to one another, the latter are parallel. The weight of each lever is 25 grammes; the length of the long arm is 40 cm., and its ratio to that of the short arm is at present 10 to 1; but this ratio can, if desired, be increased to 20 to 1. At the free end of the long arm is a small V-shaped frame, which carries a light pen furnished with a counterpoise, similar to those used in the meteorological instruments constructed by MM. Richard of Paris. The levers are arranged so that they are perfectly free throughout their whole range, passing one over the other without striking.

The instrument at Catania differs only in details. The pendulum is 26 metres long and 300 kg. in mass, and the horizontal levers are made of thin aluminium plate.

In both apparatus, the strip of paper on which the registration is made is 14 cm. in breath, and is driven by a brass cylinder 60 cm. in circumference, which rotates once an hour. A strip of paper, which costs one franc, lasts for about seven days, and can be used at least four times, twice on each side, so that the daily cost is less than four centimes. Paper is also wrapped round the driving cylinder to prevent the loss of any part of the diagram, in case the moving strip should come to an end unexpectedly.

For ten seconds at the beginning of every hour, the traces are interrupted, the levers being raised from the paper by means of a system of levers connected electrically with a chronometer. The experience of five years with another instrument shows that this is the best of the methods which have been devised for marking the time. The subsequent movement of the levers does not seem to be in the least affected by their removal, and the missing part of the diagram is so small that it can be reconstructed with ease.

The diagrams corresponding to distant earthquakes which are obtained with this seismometrograph are too large to be conveniently reproduced. The velocity of the paper being so great (60 cm. an hour),[1] the diagrams are exceedingly clear, showing the individual undulations so distinctly that all the elements of the motion and the epochs of the different phases can be determined with great precision.

Professor G. Grablovitz's Geodynamic Levels.—For many of the details given below I am indebted to the kindness of Professor Grablovitz. The levels are installed in the R. Osservatorio Geodinamico of Casamicciola, in the island of Ischia, one being directed north and south, and the other east and west.

The account of these levels is contained in the following papers:—

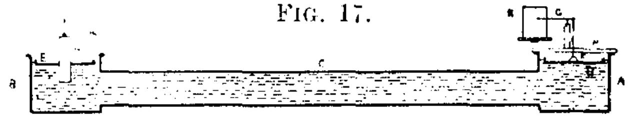
1. 'Livelli geodinamici a registrazione continua:' 'Boll. Soc. Sismol. Ital.,' vol. i. 1895, pp. 39-43.
2. 'Nuovi metodi per indagini geodinamiche:' *Ibid.* vol. ii. 1896, pp. 41–61.

[1] The reasons which have led Dr. Cancani to regard this as the most suitable velocity for the study of pulsations from a distant earthquake are given in a valuable paper, 'Sugli strumenti più adatti allo studio delle grandi ondulazioni provenienti da centri sismici lontani' (*Rend. delle R. Accad. dei Lincei*, vol. iii. 1894, pp. 551–555).

Each level is 2·50 metres long, and consists of two vessels A, B (fig. 17) 30 cm. in diameter and 25 cm. high, communicating with one another by means of a tube C, 15 cm. in diameter. The level is filled with water, and, to prevent evaporation, floats, D, E, consisting of zinc dishes 28 cm. in diameter with a rim 3 cm. high, are placed in the vessels at each end, and these again are surrounded with a stratum of oil. In the centre of the float D there rests a weight F of 100 grammes, connected by a wire with the end of the short arm of the amplifying lever G, the fulcrum of the lever being fixed to a plate H resting on top of the vessel A. The arms of the levers are 3 mm. and 15 cm. in length, so that the movements of the float are magnified fifty times. The longer arms of the levers were at first furnished with pens filled with ink, but for these were afterwards substituted points writing on smoked paper, which give much clearer diagrams. The paper is wrapped round a cylinder K, rotating on a vertical axis once in 53 minutes, and drives the paper under the pen at the rate of $5\frac{1}{2}$ mm. a minute. The levers of the two levels are arranged with their pens on the same vertical line, and about 6 cm. from one another.

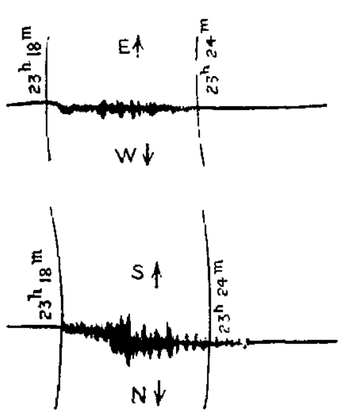
In order that the records may not be superposed after a complete revolution is made, a cylinder L, 4 cm. in diameter, is lowered from a drum, driven by another clock, into the vessel B. As it becomes immersed in the water the registering float D is slowly and gradually raised, and the pen in consequence traces a continuous spiral on the paper. As the cylinder rotates once in 53 minutes the diagram for each component consists of twenty-seven lines, the distance between consecutive lines being about a millimetre. To determine the time of any displacement of the float, a trace is impressed when the paper is put on and taken off, as well as at some intermediate time about equidistant from the ends of the 24 hours. Or, if desired, an automatic hourly trace could be made by electric connection with a chronometer.

FIG. 17.



The lines of the spiral are parallel and equidistant. Except when the instrument requires sensitising, the registration proceeds without jumps, showing that it is sensible to very small changes of level. Professor Grablovitz informs me that he has not been able to determine the smallest tilt which the levels can detect, but a displacement of the writing-point of half a millimetre, corresponding to a tilt of the ground of 2″ can generally be read with certainty.

FIG. 18.



The levels do not seem to be affected by the tremors of passing carts, &c., but they are sensible to certain seismic movements. They will not register slow movements taking place in a horizontal direction, for in such cases the water receives no displacement relatively to the tubes. Nor do they seem capable of recording the long-period pulsations of very distant earthquakes. For instance, on June 15 of the present year the horizontal pendulums at

Casamicciola revealed oscillations of 10″, due probably to the earthquake which caused the great sea-waves in Japan; but, at the same time, the levels were not affected, though the corresponding traces on their records would have been 2·5 mm. in length.

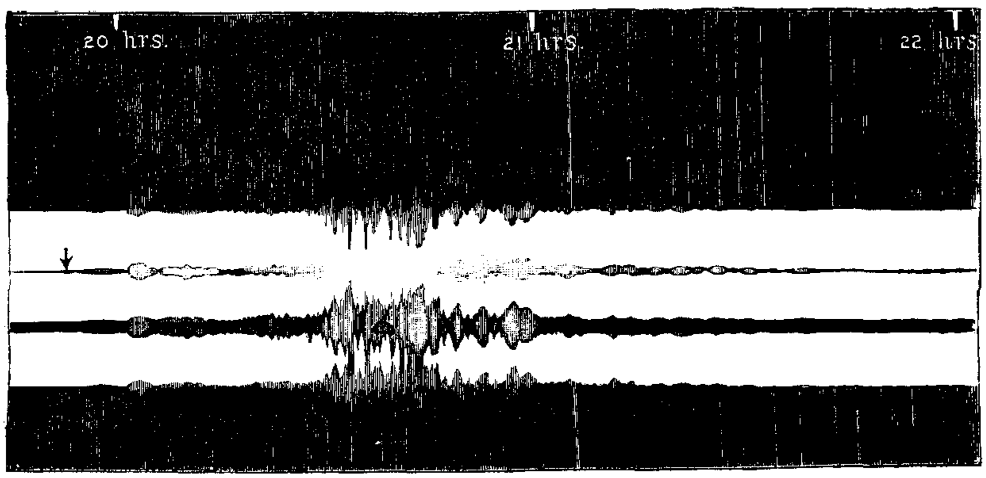
The most marked diagram so far obtained is that which was due to the severe earthquake in Carniola on April 14, 1895 (see fig. 18, in which the scale is half that of the original diagram). The curve in this case was, however, obtained before the employment of smoked paper, so that it is not so clear as that of a similar earthquake at the present time would be.

APPENDIX.

Notes on Special Earthquakes. *By* Professor J. Milne.

About 11.30 P.M. on August 26, 1896, a diagram was obtained which may represent an earthquake that occurred in Iceland on that date. It shows three maxima. A much more remarkable record, however, is one commencing as a series of minute tremors at about 8.23 A.M. on August 31.

Fig. 19.—Japan Earthquake; Carisbrooke Castle Record.



It is shown on the photogram from Shide, and also from that at Carisbrooke Castle (fig. 19), and the times of marked phases of motion in G.M.T. are as follows:—

—	Carisbrooke Castle	Shide
	H. M. S.	H. M. S.
1. Exceedingly minute tremors, August 30	20 23 6	Too faint to be visible.
2. First decided tremors	20 31 46	20 31 42
3. Heavy motion commences	20 57 6	20 56 49
4. First maximum (about)	21 4 26	21 1 0
5. The maximum	21 14 26	Not calculated.
6. Heavy motion	21 19 46	,, ,,
7. ,, ,,	21 23 6	21 24 43
8. ,, ,,	21 27 46	Not calculated.
9. End of tremors	23 16 20	22 59 36
Duration of disturbance	2 53 20	—
Duration of preliminary tremors	0 34 0	—

The reason that phase No. 1 is not shown at Shide—and it can only be seen in the Carisbrooke record with the help of a strong magnifying-glass —is apparently due to the fact that the Shide lamp gives a light which is smaller and therefore feebler than that at Carisbrooke. The photograms from the latter station have therefore a definition sharper than those from Shide. Carisbrooke records are also freer from 'tremors' than those at Shide.

Phases 2 and 3 respectively differ by 4 and 17 seconds; but inasmuch as the Carisbrooke time was regulated by comparisons with an ordinary watch, it is remarkable that these well-defined periods are so closely coincident.

The difference in duration at the two stations is also probably due to difference in definition of the photograms.

I do not know where this shock originated, but because the daily papers tell us that there was a severe earthquake in Japan on August 31, and because the preliminary tremors have outraced the principal motion by 34 minutes—which indicates an origin at a distance of about 6,000 miles—the inference is that the above records refer to an exceedingly violent adjustment of crumpling strata, probably in Japan. If this inference is correct, then in that country, in its own time, a violent earthquake took place on August 31 at a few minutes past 5 P.M.