SUGGESTIONS
FOR THE
SYSTEMATIC OBSERVATION
OF
EARTHQUAKES,

BY

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BY

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Although the remarks made in the following paper on the systematic observation of Earthquakes are applicable to seismic areas in general, the district to which I make especial reference is the Northern portion of Japan.

To be possessed of what is popularly known as an earthquake machine and to take its records, although they may tell us something, unless the work be systematically carried out in conjunction with the instruments of other observers, our efforts are relatively of but little value.

Earthquake machines are of different kinds, and those we select to work with depend upon the objects we wish to attain.

Among the principal objects which we have in view, the following may be enumerated.

1st.—The determination of the districts from which the earthquakes we so often feel originate.

2nd.—The determination of the nature and cause of these disturbances.

This second object involves the determination of the magnitude and period of the movement, and its variation during the time that the movement continues. The variation in movements at one station as compared with another. The velocity with which the movement is propagated, which in itself involves a determination of the time of arrival of a shock at different localities, &c.

From observations such as these we are able to make important deductions as to the cause of the disturbance, whether, for instance, it is a motion produced by a blow giving rise to waves of compression and distortion, whether it is the result of a sliding and shearing in the crust of the earth, simply causing a wave of distortion, or whether the motion is a combination or resultant of these two forms of disturbance.

Observations like these would throw important light upon the effect produced in opposing or altering the character of an earthquake by variation in the topographical or geological features of the district through which it passed.

From the accumulation of records, the relation between the occurrence of earthquakes and various meteorological and astronomical phenomena—as for instance, the changes in season, the phases of the moon, the tides etc.,—might be studied.

Earthquakes which have their origin beneath the sea might be partly studied with the assistance of a few properly located tide gauges, which in addition would give records of value to the hydrographer, the navigator, and if worked in conjunction with permanent marks upon neighbouring cliffs, the geologist would obtain information respecting elevation.

As a result of these latter observations, areas of elevation might possibly be found to be those where through faulting earthquakes were numerous.

Having arrived at conclusions respecting the areas of most frequent disturbance, observations might be entered on to determine by means of delicate observations whether

the smaller earthquakes to which the ordinary instruments are not sensible are in any way the forerunners of the larger motions, and at the same time, whether by the observation of these earth tremors we are more successful in reducing the motion of the earth's crust to laws than we have been with our observations upon the larger disturbances.

Briefly these are a few of the principal objects which are before the experimental seismologist, and the next point is to consider how these objects may be attained. This I will treat of as follows:—

1st.—A description of the instruments which I would suggest might be employed.

2nd.—An epitome of the relative merits of the various instruments, together with a few examples of actual records obtained from such instruments.

3rd.—The installation of seismic observatories,—their cost, etc.

I.—THE INSTRUMENTS.

1.—A Time Taker.—The usual method which is employed in order to obtain the time at which an earthquake is felt, is by means of some contrivance easily affected by a shaking to cause a time piece to stop. The only objection to this method, which is a system employed by Professor Palmieri and recommended by Mr. Mallet, is that after a shock the clock has to be restarted, and for ordinary observers situated at different stations this is a difficult matter, involving some operation, as for instance, the interchange of telegraphic signals to enable them to reset their clocks so that they may be again easily compared.

Instead, therefore, of employing the old method, which I gave up after having had some years of experience of it, I employ a method which is as follows.

A Clock C with a central seconds hand is taken, (See

Fig 1). My own clock is driven with weights and has a long pendulum beating seconds, but a small clock beating half seconds would be preferable. The hour hand and minute hand are each produced outwards, and then bent at right angles,—the hour hand *h* being the longest, the minute hand *m* next in length, and the seconds hand *s* the shortest. These are all tipped with small pieces of cork, and the points of all of them move in the same plane. These points are from time to time smeared with a little ink composed of glycerine and lamp black.

A light flat wooden ring R R faced with a varnished paper dial, the divisions on which correspond to the divisions on the clock dial, is so arranged that at the time of a shock it can be quickly advanced until it touches the three points covered with ink, and then drawn back. By so doing the hour, minute and second of the shock are indicated on the varnished face of the ring. This backward and forward motion of the ring is effected by means of a crank and connecting rod K, the crank being caused to make half a turn by means of a pulley P, which is turned by a falling weight W. At the time of a shock an electro-magnet M in connection with a circuit closer (yet to be described) pulls a catch away from the pulley, and the crank pin which is at its highest position moves to its lowest position, whilst the weight falls to the bottom of the box like carriage S on which the whole of this apparatus is arranged. This half turn of the pulley causes the ring to be pushed out towards the clock and then to be withdrawn, and the time at which this operation takes placed is marked on the ring R, and the clock is neither stopped nor practically retarded.

The dimensions of this arrangement depend upon the size of the clock. In my apparatus the ring R has a diameter of 26 cm. and the pulley P a diameter of 4.5 cm. The carriage S is 32 cm. long and 18 cm. deep. It runs in grooves on a board provided with three leveling screws which rest on a stand placed in front of the clock.

2.—A Seismometer for records on stationary plates.—In this apparatus a pendulum so controlled by friction that for small displacements it is "dead beat," is used as a steady point. To magnify the motion of the earth relatively to this steady point, a lever or index furnished at its lower end with a sliding needle working on a smoked glass plate is employed. This instrument shews very clearly the maximum amplitude of the earth's motion and whether that motion has been simply in one direction or in many. It will be understood by reference to Fig 2. B B B B is a box 113 cm. high and 30 cm. by 18 cm. square. Inside this box a lead ring R, 17 cm. in diameter and 3 cm. thick is suspended as a pendulum from the screw S. This screw passes through a small brass plate P P which can be moved horizontally over a hole in the top of the box. These motions in the point of suspension allow the pendulum to be adjusted.

Projecting over the top of the pendulum there is a wooden arm W carrying two sliding pointers H H resting on a glass plate placed on the top of the pendulum. These pointers are for the purpose of giving the frictional resistance before referred to. If this friction plate is smoked, the friction pointers will write upon it records of *large* earthquakes independently of the records given by the proper index, which only gives satisfactory records in the case of shocks of ordinary intensity. Crossing the inside of the pendulum R, there is a brass bar perforated with a small conical hole at M. A stiff wire passes through M and forms the upper portion of the index I, the lower portion of which is a thin piece of bamboo. Fixed upon the wire there is a small brass ball which rests on the upper side of a second brass plate also perforated with a conical hole, which plate is fixed on the bar O O crossing the box.

If at the time of an earthquake the upper part of the index I remains steady at M, then by the motion at O, the lower end of the index which carries a sliding needle at g, will magnify the motion of the earth in the ratios M O : O g. In my instrument O g is about 17 cm.

The needle g works upon a piece of smoked glass. In order to bring the glass into contact with the needle without disturbance, the glass is carried on a strip of wood K hinged at the back of the box, and propped up in front by a loose block of wood Y. When Y is removed the glass with K, drops down out of contact with the needle. The box is carried on bars of wood C C, which are fixed to the ground by the stakes A A.

3.—Reproduction of Records.—After a record has been obtained, the glass is coated with photographer's varnish, and if copies of the record are required the glass is photographed by the "blue process" so well-known to engineers. This process is as follows.

First prepare the two following solutions.

$1\frac{7}{8}$ oz. Citrate of Iron and Ammonia + 8 oz. pure water.
$1\frac{1}{4}$ oz. Red prussiate of Potash + 8 oz. pure water.

These two solutions are prepared separately and afterwards mixed in a dark coloured glass bottle, which must be kept in the dark.

Sheets of paper are prepared by smearing them with a sponge dipped in the above solution. This operation is performed in a dark room where the sheets of paper are allowed to dry.

When required for use a sheet of prepared paper is placed on a board with the prepared face which has a yellowish green colour, upwards. The glass with the diagram is laid on this with the varnished side downwards, and is held in position with drawing pins. This is exposed to the sun for one or two minutes, after which the glass is removed, and the paper which has changed colour is plunged into water and *thoroughly* washed. The paper is then dried.

Instruments to write on moving plates.—As it is desirable for certain purposes to obtain records in which the direction and extent of each vibration is separately represented, various contrivances have been devised to cause the plate on which the record is being written to be itself in motion at the time of a shock.

4.—Double Bracket Seismograph.—A form of instrument which has already yielded some fairly good results is Mr. Gray's Double Bracket Seismograph. For a description of this instrument see Phil. Mag. September, 1881.

5.—Conical Pendulums.—This instrument, which is the invention of Mr. Thomas Gray is described in the Philosophical Magazine, September, 1881. The principle on which the instrument works and the form in which I am employing it, will be understood from Fig. 3.

A pair of Pendulums are suspended in planes at right angles to each other. The bob B of each of these pendulums is pivoted a short distance from the end of a light horizontally placed lever which forms the writing index I, the short end resting as at M, against the side of a post S. The weight B is carried by a thin wire, the upper end of which is attached to a screw vertically above the fixed end of the lever.

A motion in the direction M I in the elevation is not recorded by the pendulum shewn in the same sketch, but is fully recorded by the second pendulum shewn in the plan. Usually each of these pendulums will record a *component* of the motion, which components have to be combined when analyzing the record.

It will be observed that one of the indices is cranked so that the two pointers may write side by side. It will be also observed that the frictional resistances are extremely small, there only being the friction of the sliding writing needle and a *slight* friction at the pivot M.

6.—*The Bracket Seismograph* (See Fig. 4).—The principle involved in this instrument of supporting a heavy mass in neutral equilibrium on a lever free to turn round a vertical axis, was first employed by Professor W. S. Chaplin of the Tokio University. It was subsequently employed by Mr. T. Gray and also by Professor Ewing. Important changes made in this instrument by Professor Ewing were to reduce its dimensions, pivot the heavy mass, and add multiplying indices. (See Proceedings of the Royal Society Vol. XXXI., Transactions of the Seismological Society Vol. II. and Transactions of the Asiatic Society of Japan Vol. IX. Part I. page 40.)

The form in which I have employed this instrument is a slight modification of that described by Professor Ewing. It will be understood from Fig. 4.

W is a heavy cylinder (a brass tube filled with lead) pivoted at its upper and lower end and free to turn on its axis in the bracket B. The bracket B is supported on the wooden post S by means of a pivot at its lower corner which points in the direction of the upper pivot of the weight, and a knife edge K in the front part of the triangular hole in a small plate P fixed on the top of S. A light piece of bamboo I terminated with a] shaped piece of Aluminium A forms the index. In the upper and lower part of the Aluminium there are small holes sufficiently large to allow a thin needle to pass and drop down upon the surface of a smoked glass plate on the carriage C. The post S is fixed on a board B screwed to the head of two stakes R R forming a bridge, close underneath which the glass plate can pass. In the plan it will be seen that there are two of these brackets placed at right angles to each other, one of them having its index cranked at

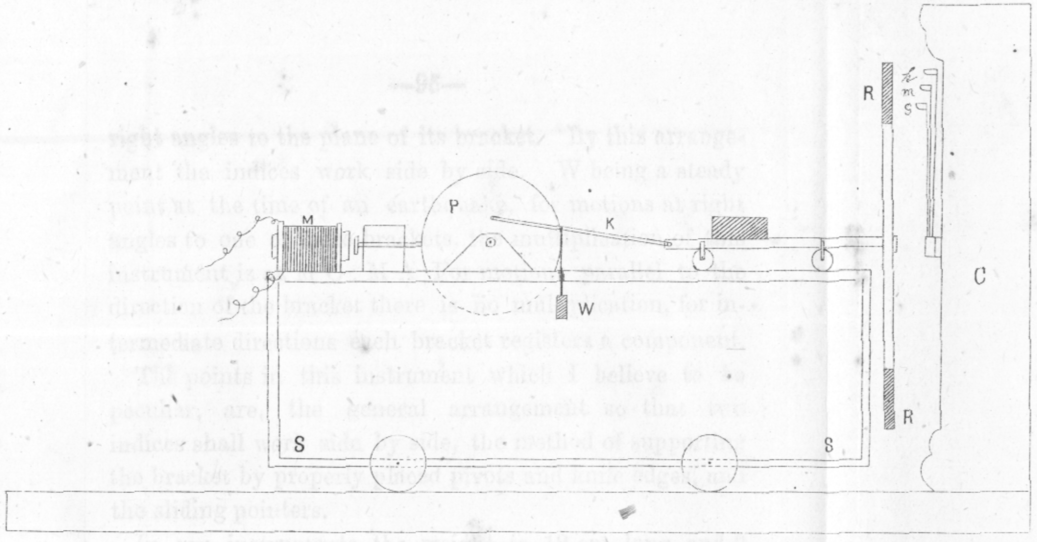


Fig 1.

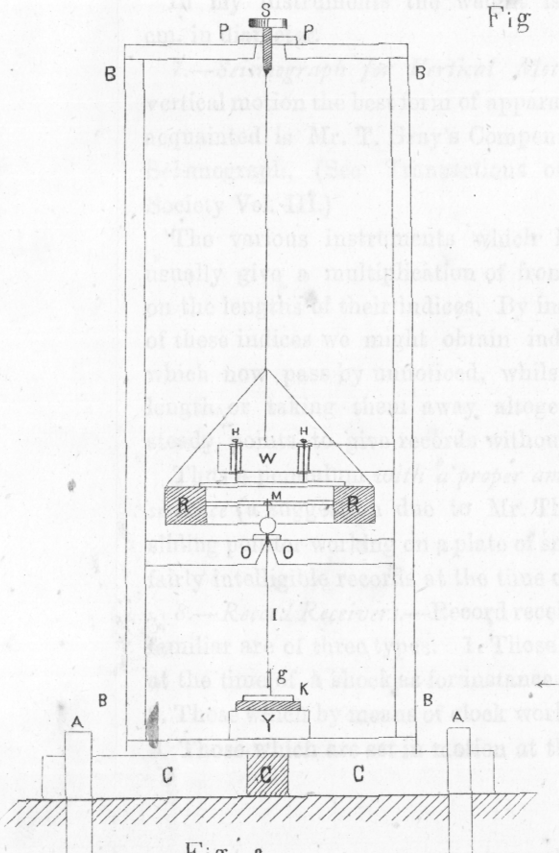


Fig 2.

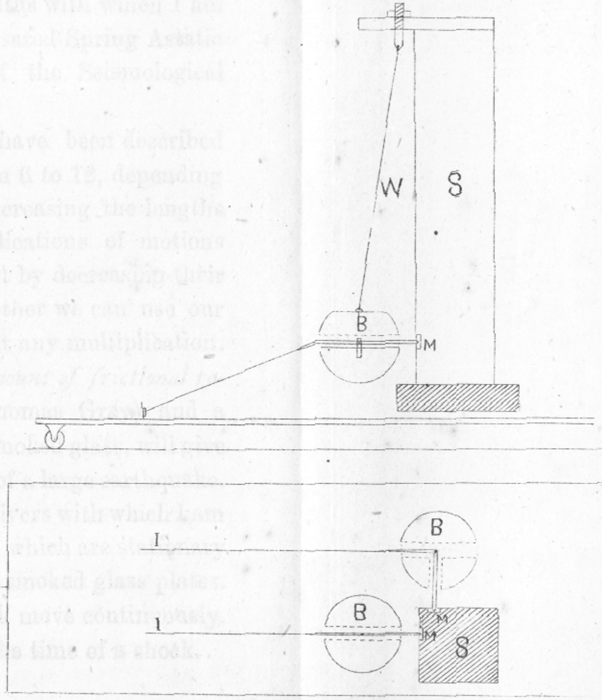


Fig 3

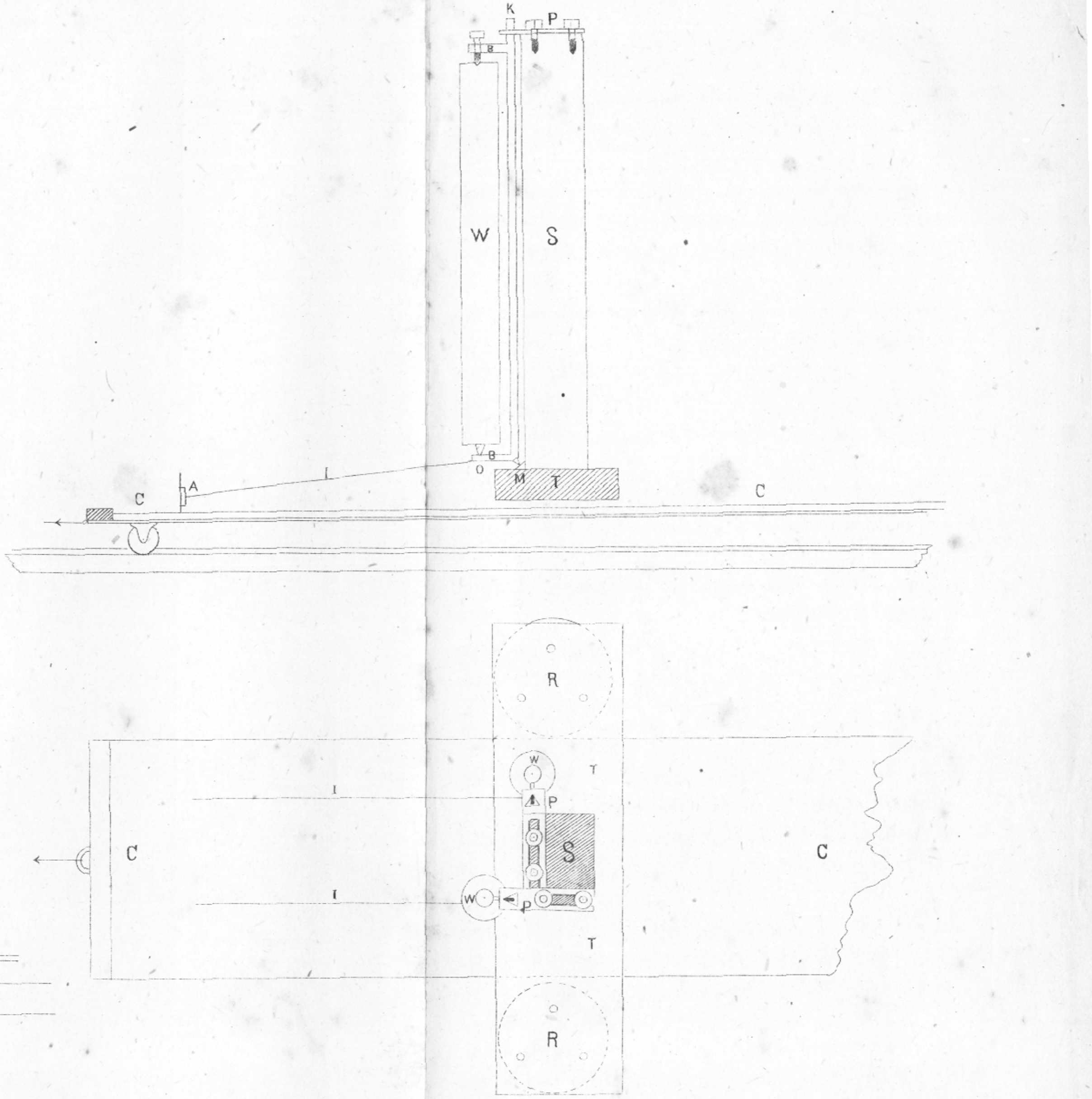


Fig 4.

right angles to the plane of its bracket. By this arrangement the indices work side by side. W being a steady point at the time of an earthquake, for motions at right angles to one of these brackets, the multiplication of this instrument is as M O : M A For motions parallel to the direction of the bracket there is no multiplication, for intermediate directions each bracket registers a component.

The points in this instrument which I believe to be peculiar, are, the general arrangement so that two indices shall work side by side, the method of supporting the bracket by properly placed pivots and knife edges, and the sliding pointers.

In my instruments the weight is 13 cm. long, and 3 cm. in diameter.

7.—*Seismograph for Vertical Motion.*—For recording vertical motion the best form of apparatus with which I am acquainted is Mr. T. Gray's Compensated Spring Astatic Seismograph. (See Transactions of the Seismological Society Vol. III.)

The various instruments which have been described usually give a multiplication of from 6 to 12, depending on the lengths of their indices. By increasing the lengths of these indices we might obtain indications of motions which now pass by unnoticed, whilst by decreasing their length or taking them away altogether we can use our steady points to give records without any multiplication.

Thus a pendulum *with a proper amount of frictional resistance* (a suggestion due to Mr. Thomas Gray) and a sliding pointer working on a plate of smoked glass, will give fairly intelligible records at the time of a large earthquake.

8.—*Record Receivers.*—Record receivers with which I am familiar are of three types. 1. Those which are stationary at the time of a shock as for instance smoked glass plates. 2. Those which by means of clock work move continuously. 3. Those which are set in motion at the time of a shock.

Continuously moving record receiver (See Fig. 5).—One form of these record receivers is a circular glass plate which by means of clock work is caused to revolve continuously. On this the pointers of the seismograph rest and so long as there is no earthquake they continually retrace the same circle. At the time of an earthquake they move back and forth across the circles they have been making which theoretically are fine lines and leave a record of the earthquake.

This form of instrument, is a form of Chronograph and was first employed in connection with earthquake investigation by Prof. W. S. Chaplin. Subsequently it was used by Prof. Ewing. As employed by Prof. Ewing the clock and stand are separate pieces of apparatus. A more compact and cheaper, form of apparatus, is the instrument shewn in Fig. 5.

P is a glass plate about 38 cm. in diameter revolving on the axle M. By unscrewing the nut N the plate can be easily removed. It is caused to revolve by a falling weight driving the drum A and the gearing B. C. D. The gearing E. F. G. H. I. J. drives the governor T.

T is a revolving trough containing a small quantity of glycerine. Projecting into this, there is an adjustable vane V. By the rising up of the liquid due to centrifugal force the vane is immersed and resistance offered to the motion of the clock. The action is a powerful one. There is also a governing action similar to that of a fly wheel. The great recommendation however is that as the liquid is in rotation at the time of an earthquake it is not likely to be affected, whilst in a governor like Airy's it is possible that by the shaking, the liquid is disturbed and the governor is caused to act when not required. The number of teeth in the various wheels and their dimensions are are indicated in the figure.

Record receivers set in motion at the time of a shock,

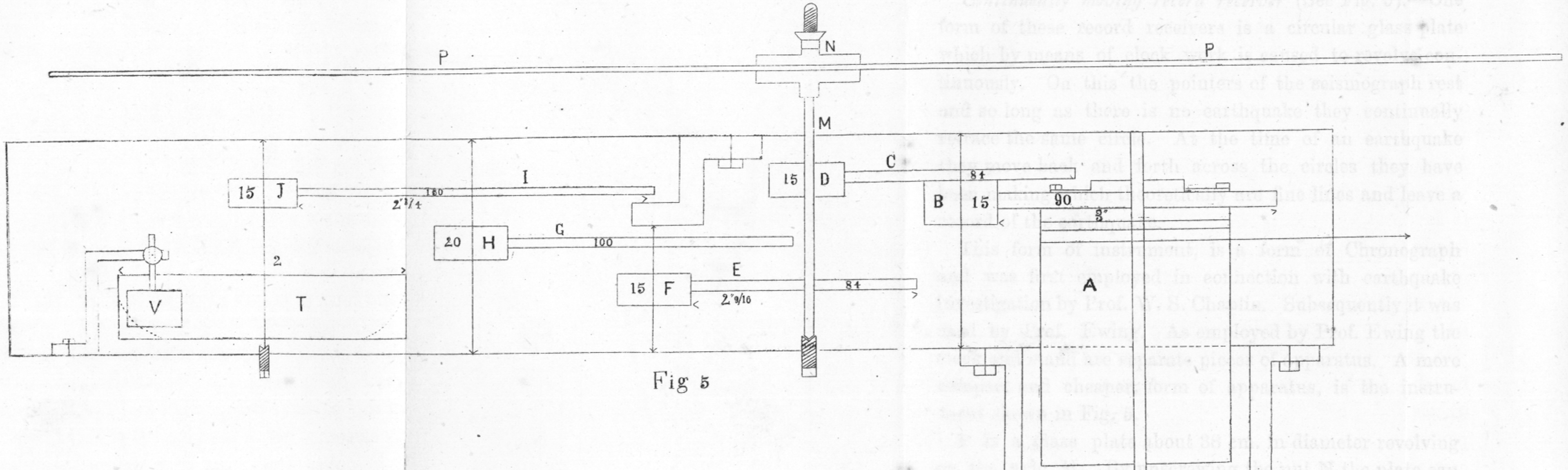


Fig 5

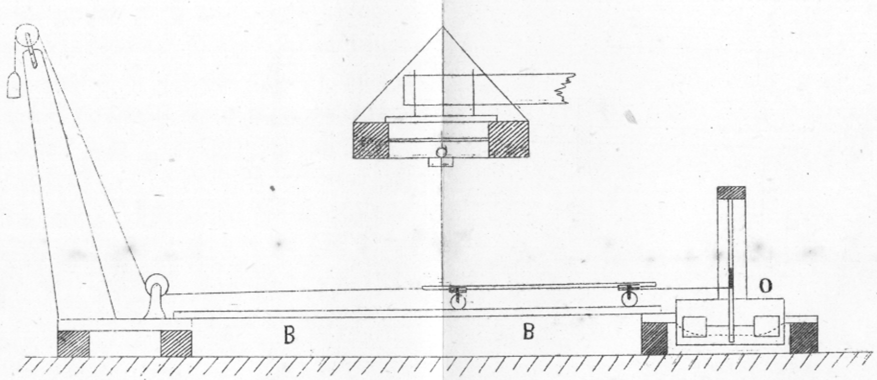


Fig 6

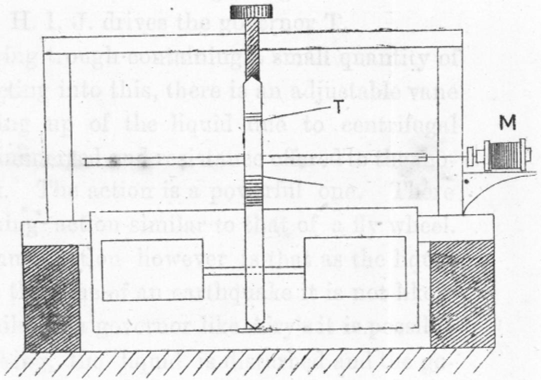


Fig 7

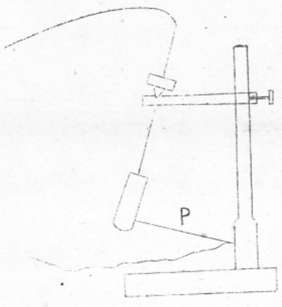


Fig 8

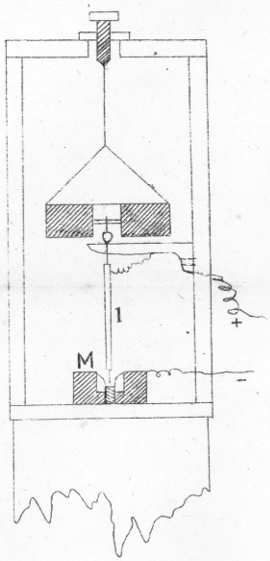


Fig 9

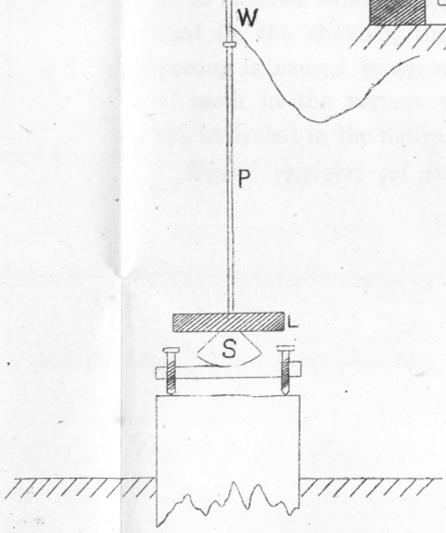


Fig 10

In one form of record receiver I have a strip of smoked paper wrapped on a drum. The axle of this drum is a prolongation of the key of the striking machinery of a small American spring clock. At the time of an earthquake an electro-magnet draws back a pin holding the air fan of the striking apparatus and the drum revolves. As it revolves and the pointers of the seismograph are writing their records, it is caused to travel horizontally. It is so arranged that when the striking apparatus is set free the balance wheel of the clock is stopped and a record of time is obtained.

A second form of record receivers is as follows (See Fig. 6).

A strip of smoked glass about 77 cm. long and 18 cm. broad rests on a light three wheeled carriage C. The wheels of this carriage are grooved and run on three copper wires stretched along the board B to form rails. The carriage is pulled by means of a falling weight W. A string attached to the back of the carriage, the other end of which is wound round the axle of a large fan revolving in a tin vessel O containing oil, regulates the motion. The fan which has a diameter of about 18 cm. is shewn on a larger scale in Fig. 7. It is held held by a pin, which at the time of an earthquake is drawn back by the electro-magnet M, in connection with a circuit closer. When the pin is drawn back, the weight as it falls pulls the carriage along slowly, while the pointers of the seismograph write the movements of the ground upon its surface.

A check upon the regularity of the plate's motion is obtained by causing a small pendulum (Fig. 8) the upper part of which is a flexible spring, to mark time upon it—a method proposed by Prof. Ewing. The pendulum is set free by the first turn of the fan winding up the thread T, which pulls away a small prop P which keeps the pendulum deflected.

9.—Circuit Closer.—It has been seen that in order to set the two last mentioned instruments in motion and also to take the time of an earthquake, it is necessary to employ some instrument, which with a slight disturbance will close an electric circuit. This is accomplished by means of the instrument shewn below, which to a great extent is a reproduction of the pendulum seismograph upon a small scale. (See Fig. 9.)

Running down the index I of this instrument, there is a fine Copper wire terminating in a platinum point, This hangs freely in the center of a depression in a small cup of Mercury M. This depression is formed by driving a small iron pin in the bottom of the wooden cup which contains the Mercury, after the fashion of Palmieri's circuit closer. The mercury forms the other pole of the circuit. Should the index move in any direction excepting vertically the circuit is immediately closed. The whole is contained in a box about 34 cm high and 14 cm square.

10.—A Tremor Indicator.—The above instrument may be employed as a tremor indicator. Its sensibility depends upon the relative lengths of the upper and lower portions of the index. When made very sensitive it may be employed as a tremor indicator, each tremor being recorded by an electro-magnet deflecting a pencil describing a circle on a revolving disc. A cheap American spring clock in which the minute hand has been replaced by a wooden disc, will act as a receiver of these records. In order to prevent the pencil (which is attached to a lever moved by an electro-magnet each time the circuit is closed) continually tracing the same circle, the clock may be mounted on wheels and caused to wind itself along a stretched string passing round the hour axle.

11.—A Mechanical Starter.—Instead of employing electrical means to start record receivers and apparatus to take the time of an earthquake, it is evident that these might be set in motion if the catches which hold them could be released.

The best mechanical method of doing this, so far as my experience has gone, is by causing a small weight connected by a string with the catch, to fall, in consequence of which the latter receives a sudden jerk and the machine is set free.

In order that a weight should fall with a slight motion of the ground I proceed as follows. (See Fig. 10.)

S is the segment of a sphere about 4.5 cm radius with a center slightly above C. L is a disc of lead about 7 cm thick resting upon this segment. Above this there is a light pointer P. about 30 cm long.

This is kept vertical by means of the leveling screws in the board on which S rests. On the top of this pointer a small cylindrical piece of iron W is balanced. When the table or head of the post on which this is standing is shaken, S C P tends to rotate round some point near to C and therefore the motion at the base of S is magnified at the upper end of the pointer, and a slight motion of the ground becomes sufficient to overturn the weight which otherwise would not have fallen.

This contrivance which, will be recognized as involving the same principle as Mr. Gray's Rolling sphere seismograph, although it is the best of the mechanical contrivances with which I am familiar, is not nearly so sensitive as the electric circuit closer.

II.—THE RESULTS OBTAINED FROM INSTRUMENTS.

Time Taker.—A set of instruments which will determine the time at which any selected portion of a disturbance took place at a number of stations, I regard as being amongst the most important of all earthquake instruments.

In order to determine the origin from which an earthquake proceeded we are usually recommended to prolong to their intersection the direction of motion of the ground as observed at several stations. Such an intersection ought to give the *epicentrum* or point above the origin. With certain earthquakes especially perhaps those which are severe, this method may lead us to results which are more or less definite. Unfortunately so far as my own experiments are concerned it will often happen that the instruments (and many instruments based upon different principles have been employed) give for the same disturbance a variety of directions,—clearly shewing that the direction in which the ground vibrates has not always a constant direction. Sometimes we have reasons to believe that the principal vibrations of a shock are *transverse* to the direction in which it is being propagated.

For these reasons, in order to determine with certainty the direction in which a shock is propagated, accurate time observations must be obtained.

An objection which may be raised to all ordinary time-takers is that we are not sure at which portion of the shock they came into operation. By placing in the same circuit as the time-taker a second magnet which relieved a small pendulum which fell upon the plate of a continously moving record receiver, I can say that the objection above referred to, is for practical purposes unfounded. With this arrangement it has been shewn that sometimes the time has been taken a little *before* there has been any visible record upon the continuously moving receiver, at other times it has been a little after. Whether the time shall be taken before or after the commencement of a record, depends almost entirely upon the amount of multiplication we give to the circuit closer as compared with the multiplication of the indices of our seismograph. Because earthquakes as written upon continuously moving receivers do not appear to have either a definite commencement or end, our only chance of obtaining absolute time is to pick out some conspicuous vibration and calculate the intervals of time, between the times at which it was recorded at two or more of our stations. This is a method which has been insisted upon by Professor Ewing. Previously and subsequently it was practically experimented upon by Mr. Gray and myself in connection with our experiments upon artificial earthquakes.

In the artificially produced disturbances there appeared to be great uncertainty as to corresponding vibrations as recorded at different stations. With actual earthquakes the difficulties will some times not be so great. (See Records of Artificial Earthquakes p. 116, and remarks upon continuous record receivers.)

However, as the stations I propose to use are at long distances apart, the errors in the method I suggest, will have but little if any significance.

Pendulum Seismograph.—The great advantage of a pendulum seismograph working on a stationary plate, is that the record shews at once whether the direction of motion has been constant or whether it has been variable. The maximum extent of motion in various directions is also easily obtained.

The disadvantage of the instrument is that at the time of a large earthquake, owing perhaps to a slight swing in the pendulum the records may be unduly magnified.

On such occasions however, fairly good records may be obtained from the friction pointers, providing that the plates on which they work have been previously smoked. It might perhaps be well to use two of these instruments, one having a comparatively high frictional resistance and being "dead beat" for large displacements.

I select the following five records as *types* of the results which are obtained.

Examples of Records obtained from a pendulum seismograph which multiplies the earth's motion about 10 times.

I.—At Chiba, (16 miles E. of Tokio) 11.49.00 P.M. February 16th 1882. Here the motion has been simply in *one* direction S. 35° W. Its extent is about .9 mm.

II.—At Chiba, December 23rd, 1881 4.30 A.M. Here the motion has been in at least *two* directions N. 60° W. with an amplitude of 1 mm. and also about N. and S.

III.—At Yokohama, October 25th 1881. Here the motion has been in *several* directions, but principally about N. 5° E. with an amplitude of about .9 mm.

IV.—At Tokio, 4.15.0 P.M. March 8th 1882. Here the variation in direction of motion is more distinct than in Number III. The directions have been N. 45° E., N. 10° E., N. 60° W., etc. The maximum amplitude is about 2.2 mm.

V.—At Tokio, 7.52.12 P.M. March 11th 1882. This earthquake was rather severe. After a few small motions had produced the central record a sudden extensive motion in a direction N. 60° W. drove the index off the plate. The amplitude of this was about 6 mm. This indication is probably too great.

VI.—At Chiba, 3.29.30 A.M. March 1st, 1882. This is the record of the friction pointer writing on the glass above the pendulum. The motion is chiefly N. and S. It is only with large earthquakes that this pointer, which has no multiplication, produces a record.

VII.—At Tokio. This is a record of the above earthquake as given by the index. It will be seen that the chief motion has been in a direction between E. and E. 28° S.

Record Receivers which move and Seismographs which write on them.—Thus far I have not succeeded in finding any instrument which gives its records with a *single* index which can be used upon a continuously moving receiver, —the friction of the point of the index upon the revolving plate producing a broad line. Even with plates like those of a carriage receiver which is only set in motion at the time of a shock, the dragging action of the plates more or less vitiates the results. The best records which I have obtained with instruments having single indices have been with a double bracket seismograph on a carriage receiver, —and these only with small earthquakes. A seismograph with a single index which will give a satisfactory record upon a moving plate is much required.

The only instruments which invariably give good records upon moving plates are those which write down the motions of the earth as two components. The chief objection to these instruments is the difficulty experienced in combining the diagrams of the two indices in order to obtain the true motion of the earth. Also we are never certain as to the amount and relation between the frictional resistances of the two portions of our instrument.

The best form of a two component instrument is probably the one where frictional errors are reduced to a minimum, as for example in Mr. Gray's system of Conical Pendulums.

Such an instrument ought to be provided with sliding pointers at the ends of the indices.

Indices which are hinged and rest on a plate, insomuch as a plate never moves truly horizontally, offer a variable resistance, and as this resistance is applied at the end of a long lever it requires careful consideration.

These sliding pointers, I must remark, are not suitable for record receivers which have a continuous motion as they tend to produce a broad line.

The reason that I have for making the two pointers of my instruments work side by side is that their respective records are in the best possible position for analysis, by which I mean comparison and combination. Thus for example, we see at a glance whether there has been a difference in amplitude in two directions.

With regard to the relative advantages and disadvantages of the two types of record receivers, namely those which are continuously in motion and those which are set in motion at the time of a shock, I may as based on my own experience, state the following.

1.—Continuously revolving plates.—Disadvantages.

1.—They are comparatively very expensive.

2.—Clockwork being employed to drive the plates they require more care than those of simpler construction.

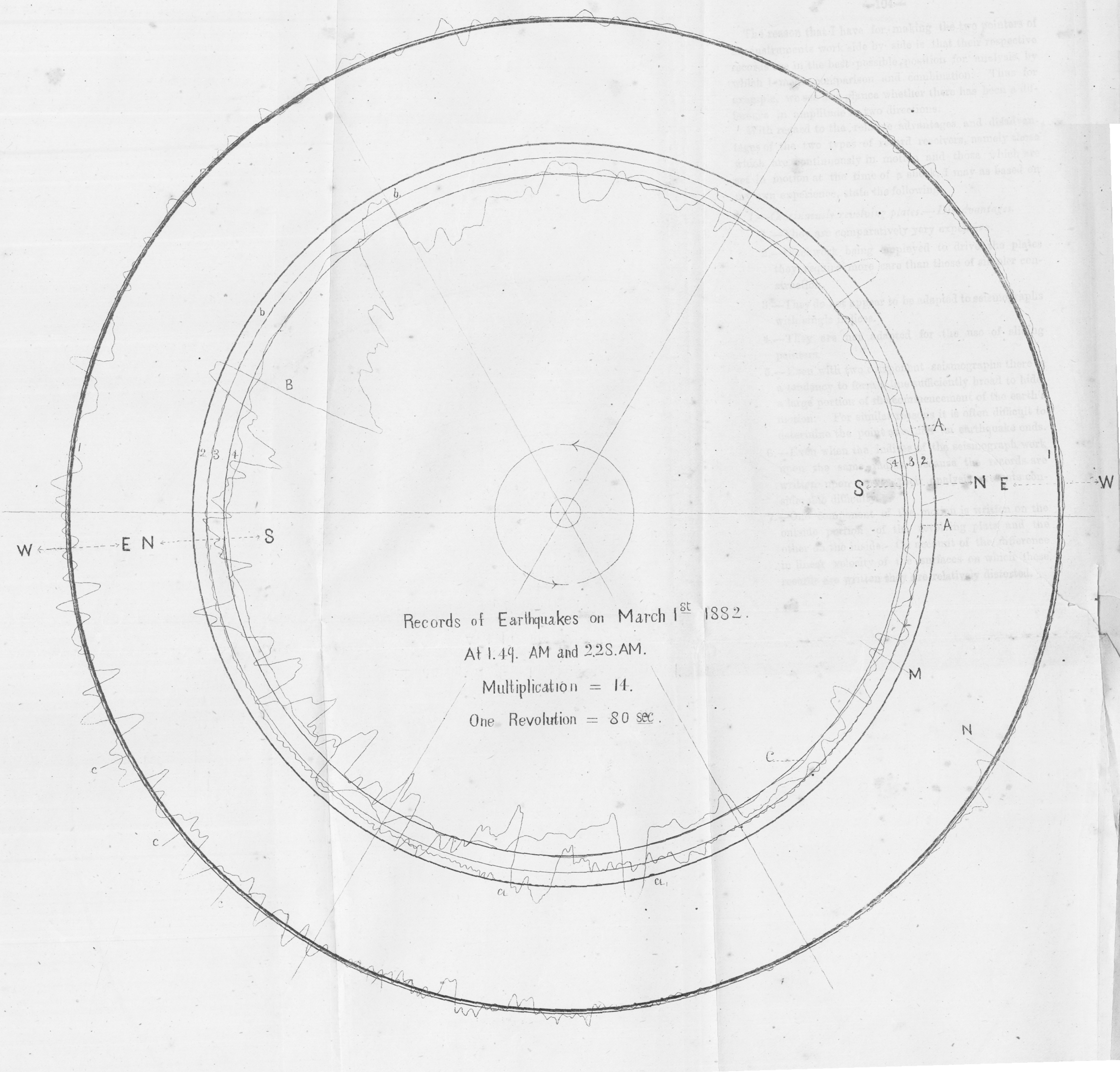
3.—They do not appear to be adapted to seismographs with single indices.

4.—They are not adapted for the use of sliding pointers.

5.—Even with two component seismographs there is a tendency to form a line sufficiently broad to hide, a large portion of the commencement of the earth's motion. For similar reasons it is often difficult to determine the point at which an earthquake ends.

6.—Even when the indices of the seismograph work upon the same radius, because the records are written upon curves, their analysis presents considerable difficulty.

7.—One component of the motion is written on the outside portion of the revolving plate and the other on the inside. On account of the difference in linear velocity of the surfaces on which these records are written they are relatively distorted.



Records of Earthquakes on March 1st 1882.

At 1.49. AM and 2.28. AM.

Multiplication = 14.

One Revolution = 80 sec.

8.—Owing to the ends of the indices describing arcs of circles and these on a revolving plate, there are considerable *practical* difficulties in determining the time of any particular vibration.

9.—If the earthquake continues for longer than one revolution of the plate, which is usually the case for large earthquakes (and these appear to be the only disturbances which admit of successful analysis) there may be confusion in consequence of one portion of the record being superimposed on another. Similarly if *two* earthquakes occur without the instrument being attended to, there is also confusion.

Objections numbers 5, 6, 7, 8 and 9, which I raise to this form of record receiver may be seen by reference to the accompanying plate which is a photograph of records obtained during the night of March 1st, 1882, in Yokohama.

Recommendation.

The great recommendation of a continuously moving circular plate is that its action, is purely mechanical and it can be at once seen whether the instrument is prepared to receive a record. This advantage is an extremely important one and is not to be lost sight of.

EXAMPLE OF RECORD OBTAINED WITH A CONTINUOUSLY REVOLVING CIRCULAR PLATE AND TWO BRACKET SEISMOGRAPHS

In this record we have the registration of two earthquakes. The first, which was small, took place at 1.49 A.M.; and the second, which was severe, at 2.28 A.M. on March 1st 1882 in Yokohama.

Each of these earthquakes is registered as two components. The outside thick circle 1 corresponds to East and West motion, while the inside thin circles 2 3 and 4 correspond to N. and S. motion, The plate takes about 80 seconds to perform one revolution, the direction of motion being that of the arrow.

At the time of the *first earthquake* circles 1 and 2 only existed and the pointers were continually tracing out the same path.

This earthquake is distinctly seen at *a* where it leaves circle number 2 and makes its way over to *b* and commenced to trace out circle number 3. On account of the gentle manner in which this earthquake commenced, the begining of the disturbance *may have been* at a_1 and the end at b_1.

The commencement and end of this earthquake are indeterminate, chiefly on account of the thickness of the circles traced out by the continued revolution of the plate before the earthquake commenced and after it had finished.

The East and West component on the outside circle Number 1, on account of the width of this circle, is entirely lost, unless it is represented by the small ripples c c, &c.

The *second earthquake* commenced at *A*, or A_1 reached a maximum at *B* and after over two revolutions of the plate died out with a very slow period about *C*.

The commencement and end of this earthquake, which I may remark has given an unusually large diagram, are indeterminate. It will also be observed that the superposition of one portion of the diagram over another also causes some difficulty. The North and South motion has evidently been the larger.

The relative positions of the two pointers are shewn by the letters *m* and *n*. The analysis of this records would have been facilitated had they been placed exactly upon the same radius.

With small earthquakes like the first of these two, the amplitude of the waves are usually too small, to be readily combined, whilst with large earthquakes like the second shock which is here recorded, the confusion produced by the superposition of waves gives rise to difficulty.

It must, however, be pointed out that there are certain facts which can be easily obtained from a record of this kind.

Thus, for instance, in the second earthquake we see,—

1.—The earthquake commenced with a period of about 4 vibrations to the second.

2.—The disturbance ended with a slow irregular period of about .5 vibrations to the second, perhaps indicating to us that the hill on which the instrument was situated, had acquired a slow swing of its own.

3.—At one portion of the disturbance the two components had almost equal amptitudes.

4.—At another portion of the shock as at B the motion appears to have been almost wholly North and South.

5.—The greatest amplitude at B is about 4 mm. (By measuring the time taken to describe a wave like B, the maximum acceleration may be calculated.)

6.—The direction in which the motion was greatest and had its maximum velocity was in towards the South, probably indicating that it is in that direction we must look for the origin of the disturbance. (This is a suggestion which I believe has been brought forward for the first time. My reasons for believing that the motion *in* towards the origin may be sometimes greater than the motion *outwards* away from the origin, I hope to bring forward at some future time).

These are points which are obtainable by a simple examination. *They are however common to the records of several other instruments.* To fully analyze the records and exactly define the character of the motion is a matter requiring time and patience.

II.—*Carriage Receiver set in motion at the time of an Earthquake.—Disadvantages.*

1.—The motion of the instrument is dependent upon certain electrical connections and these are not so readily inspected as a purely mechanical arrangement.

2.—A portion of the commencement of an earthquake may be lost, dependent upon the sensibility we give to our circuit closer.

3.—A portion of the end of an earthquake may be lost owing to our instrument not continuing to move for a sufficient length of time.

4.—See continuously revolving plates. Disadvantage No. 8.

Recommendations.

1.—The instrument is inexpensive.

2.—It is simple and not likely to be deranged.

3.—Single component instruments for small earthquakes *and also instrument to record vertical motion* have been devised which can be used upon it.

4.—Indices with sliding pointers can be employed.

5.—Two component instruments write their records upon such a receiver in the best possible position for analysis.

6.—There is no relative distortion of the two records.

7.—If an earthquake should be of long duration or if two earthquakes should occur without the instrument receiving any attention the records which have been obtained are not rendered unintelligible.

Objection number 2, it will be observed, is parallel to objection number 5 which is raised against continuously revolving plates. The portion of the commencement of an earthquake which is lost with a carriage receiver, is dependent upon the sensibility we choose to give to our circuit closer. Practically I find that this instrument may be made so sensible that a carriage can be started before the index of a seismograph with ordinary magnification has produced any visible record. (See page 117 Record I.)

Drum receiver with smoked paper set in motion at the time of a shock.—The drum covered with smoked paper shews all the advantages of the carriage receiver with the exceptions,—

1.—A surface of paper offers a greater frictional resistance to the pointers of a seismograph than a surface of glass.

2.—It is more difficult by photographic means to reproduce such records.

3.—This apparatus is slightly more expensive than the carriage receiver.

The advantages that it possesses in addition to those of the carriage receiver are,—

1.—The apparatus is more compact than the carriage receiver.

2.—The original records are more easily preserved than those upon glass.

III.—THE OBSERVATORIES.

Several instruments which have already yielded good results have now been referred to, and the next question is for us to consider how these instruments ought to be employed.

Situation of Observatories.—If we put up instruments simply at one locality, we are enabled to form a catalogue of shocks and to work out several problems relating to earthquake motion. The more important problems, for example those relating to the origin of the disturbances &c., we are unable to solve, and it therefore becomes necessary to establish several stations which work in conjunction with each other. With two stations, much more can be learnt than with one, and with three stations much more than with two. In order to obtain complete results we ought to have at least 5 or 6 stations, each properly equipped with a simple set of instruments.

The first problem that before us, is to select suitable sites for our various stations.

For northern Japan this problem has been solved as follows.

Commencing with Tokio (Yedo) as a center where earthquakes are pretty frequent, to all the important towns from 30 to 100 miles distant, bundles of post cards were dispatched to the local government offices with a request that each week one of these cards should be returned to Tokio, stating the number of shocks which had been felt. In this way it was quickly seen that the majority of shakings emanated from the North and East, and seldom if ever passed a heavy range of mountains to the South. The barricade of post cards was then extended farther Northwards, with the result of surrounding the origin of certain shocks amongst the mountains, whilst others were traced to the sea shore. By systematically persuing earthquakes it was seen that many shocks had their origin beneath the sea,—they shook all the places on the North East coast but it was seldom that they crossed through the mountains forming the backbone of the island to disturb the places on the West coast. By work of this description it was learnt that a very important group of earthquakes might be studied by a line of stations commencing at Sapporo in the North, passing through Hakodate, down the east coast of the main island to Tokio or Yokohama in the South. A farther aid to the study of this group together with the study of an important local group might be effected with the help of a few additional stations properly distributed in the plain of Musashi which surrounds Tokio.

From this example it will be seen that the choice of sites for a connected set of seismological observatories will often be more or less a special problem. If earthquake stations were placed in different directions round Tokio without preliminary investigation, it is quite possible that some of them might be so situated that they would seldom if ever work in conjunction with the remaining observatories, and therefore be of but little value.
When working on a tolerably level plain like that of Musashi, 5 or more stations might be selected at distances apart of from 15 to 30 miles, and so arranged that no three of them were in the same straight line. All stations ought if possible to be near telegraph stations so that the various observers may be able to receive appointed signals for the rating of their clocks. In Japan every day at 12 o'clock a time signal is sent throughout the empire so that the special signals are not required. In the absence of telegraphic communication, it will be necessary for the observers to be provided with means which will enable them to obtain accurate local time.

2.—Instruments to be employed:

1.—At each station there ought to be a *circuit closer* and *time taker*, so that the commencement of the disturbance may be accurately determined. If we know the times at which a shock arrived at five of our stations, and we *assume* the velocity of propagation from the origin to each of these stations to have been practically the same, then we can determine the position of the origin of the shock, its depth and velocity of propagation (see Transactions of the Seismological Society vol. II. p. 70).

If three stations are tolerably close together so that we can assume that the advancement of the disturbance has at each of them been practically parallel, then from the times of arrival at these three stations we can determine the direction in which the motion has advanced and also its velocity.

Knowing the velocity of propagation and the times of arrival at three stations, we can construct for each pair of these places a hyperboloid. The mutual intersection of these three surfaces will be the origin.

These and other methods for determining the origin of an earthquake from given elements (one of which is time) will be found in the Transactions of the Seismological Society, Vols I, II, and III.

2.—*Pendulum Seismograph.*—The results to be obtained from this instrument are briefly given on pages 101—102. In cases where the earthquake had given a decided movement in some particular direction, the prolongation of lines (through the various stations) representing the directions which had been observed, would also indicate to us the position of the origin. Among the many other possible results which might be attained, the following may be mentioned.

The manner in which earthquake motion dies out. The effect of differences in topographical or geological character of the area traversed, in altering the nature of the motion. If we know the position of the origin of the disturbance (from time observations for instance) we might possibly learn something respecting changes in direction of earthquake motion during its propagation. Something might also be learnt respecting the cause of an earthquake; whether for instance it was produced by a fault giving rise to a wave of distortion or by a blow producing in addition to distortion a wave of compression.

3.—A *carriage receiver* with a smoked glass plate or a drum receiver covered with smoked paper. In conjunction with this I should propose to use a pair of *conical pendulums* or some form of simple *bracket instrument* and a *lever spring instrument* for vertical motion. The receiver would be placed in the same circuit with the time taker.

With these instruments the period of an earthquake at different stations during different portions of a shock could be observed. Changes of phase in the direction of motion, the relation of vertical to horizontal motion, &c., might be also investigated.

These are the only instruments which I should propose to use at an ordinary station. They might be placed in a wooden hut about 12 feet long, 9 feet broad and 8 feet high at the eaves.

The approximate cost per station with the instruments which have been enumerated would be as follows:—

	Yen (paper.)
Observer's hut.................	40
Clock with Time taker	40
Carriage receiver with Conical pendulums or bracket seismograph	12
Brick Stand for Receiver ...	5
Pendulum Seismograph......	5
Wire, electric bell, battery lamp, glass, table, chair &c. say......................	98
Yen	200=Mexican dollars 133 or about £28.

This sum of 200 yen, in consequence of the high sum of 98 yen put down for sundries, is an over estimate, if instruments of the *cheapest construction* are only employed. For this sum (200 yen) it is possible by calculating the sundries as 50 yen (instead of 98) to have the seismographs, &c., more carefully finished.

The cost of five stations would therefore be under 1,000 yen ($665 or £140).

With five stations thus equipped and properly situated there is no doubt but that very much might be learnt about the earthquakes of a given district. The earthquakes I refer to are those of moderate intensity. For the proper investigation of large and destructive earthquakes although these instruments might tell us something, it is probable that special forms of seismographs like rolling cylinders would need to be employed.

At the chief stations which ought to be situated in the most active portion of the district to be examined and if possible on a rocky foundation, additional instruments might be employed,—as for instance, some form of self-recording tremor indicator, and a continuously moving record receiver. This latter instrument of the form described in this paper costs about 70 yen ($46).

If we were working along a sea coast each station might be provided with a self registering tide guage which would give indications of sea waves produced by submarine disturbances, elevation of the ground, &c. (see Transactions of the Seismological Society, Vol. II. p. 91).

Apparatus for many other special investigations might also be employed.

3.—Nine Station System of Observation.—In order to determine the speed and direction of transit of an earthquake, Professor Ewing has suggested the use of three or more stations. The principle in the plan he proposed is one which has been practically employed in experiments upon artificially produced earthquakes by Mr. Gray and myself (see page 101) (for Prof. Ewing's paper on this subject, see Transactions of the Seismological Society Vol. III).

Briefly the plan is as follows:—

Select in some tolerably level district three stations arranged to form the corners of a triangle. Let these be at distances of about ½ a mile from each other and connected by telegraph. At each of these points place a continuously revolving record receiver with seismograph. Above these receivers let there be a small pendulum (See p. 97 Fig. 8) held deflected by an electro magnet. The magnets at the three stations are placed in the same circuit with circuit closers. The cups containing the mercury in the circuit closers are so arranged as just to close the circuit. By the first disturbance at any one of the three stations, the circuit will be broken and all the pendulums will simultaneously fall upon the receivers and subsequently by their oscillations mark time.

By comparing the three records together, it is possible to calculate that the time taken by any particular vibration to cross the area where the three stations are situated.

In other words, if we assume that the disturbance has passed across the triangle of stations with a constant velocity, this velocity together with the direction of propagation of the disturbance may be calculated.

In order to determine the *epicentrum* of an earthquake, by a development of the above method, it seems necessary to establish three *groups* of the telegraphically connected observation points just described. Each of these groups, which ought to be widely separated from each other, give to us a direction for the propagation of the disturbance and if these groups be properly situated with regard to each other we ought in all cases to obtain intersections of directions which will determine the origin.

The objection to this method is that it is both complicated and expensive,—the nine record receivers alone costing 630 yen ($420 or £77).

The system of 5 or 6 stations which I have proposed for the investigation of earthquakes in a given district is undoubtedly open to several objections and it is possible for plans which might be more satisfactory to be proposed. The chief point which I have kept in view whilst making such a proposition has been that of the economy, and the endeavour to obtain the greatest number of results for the least expenditure of money.

EXPLANATION OF DIAGRAMS.

I.—Record obtained on a *Carriage Receiver* with a *Bracket Ring Seismograph* of a small Earthquake at 11.25.51 p.m., July 25th, 1881, Tokio, Japan.

The record is printed from a photograph. The dots on the record correspond to intervals of $\frac{20}{27}$ of a second, ticked on the moving plate by a pendulum. From the record we see that the plate was set in motion *before* the chief motion of the Earthquake took place. The records being written along straight lines and at the same time side by side, renders their analysis comparatively easy. For instance changes in phase of motion are seen at a glance,—thus at *B* the N. 23° E. motion was the largest, whilst at *c*, the E. 23° S. component was largest. There was no visible vertical motion.

II.—Record given by a *Conical pendulum seismograph* of a small Earthquake which occurred at Tokio on July 25th, 1881. (See Phil. Mag., November, 1881.)

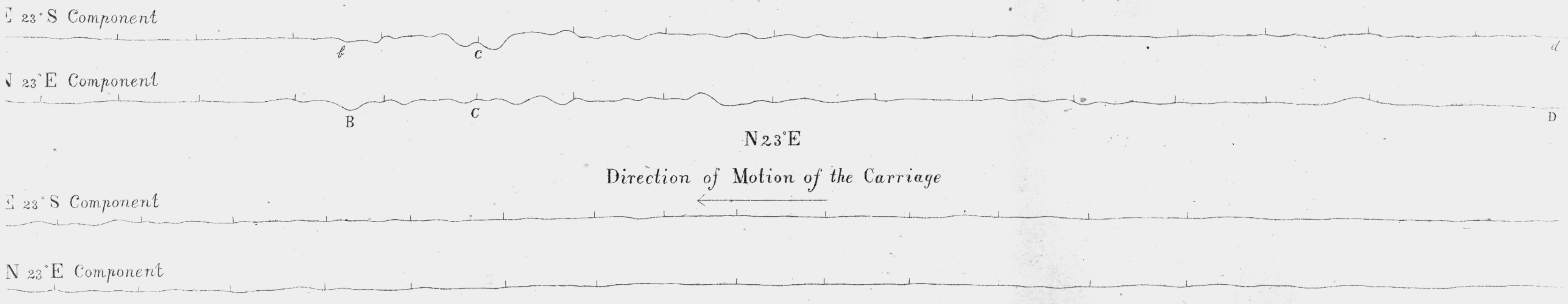
The record was written on a strip of smoked paper wound on a drum, which was started automatically by the earthquake, the commencement of which is not shewn. The line *A B C* shews the motions in a direction N. 15° E. whilst *a b c* shews the motions at right angles to this. The magnification=10. The spaces between the vertical lines=5 seconds. Observe how gradually the motion dies away.

III.—Records of an *Artificial Earthquake* produced by firing about 2 lbs. of Dynamite in a bore hole 8 ft. deep, the motion being simultaneously recorded at three stations *A B* and *C.* The instrument employed were *bracket seismographs* in conjunction with *carriage receivers.*

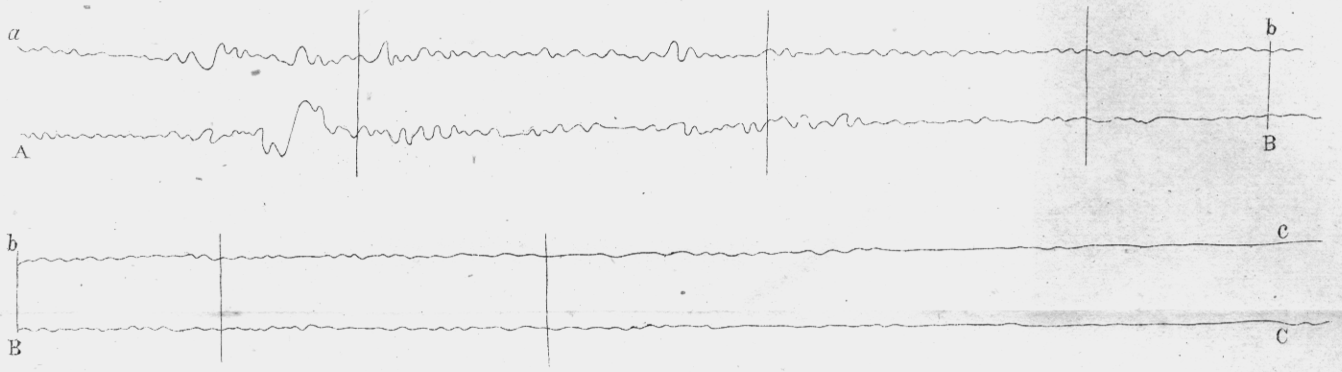
These stations which were at distances of 100, 250 and 400 feet from the explosion, were in a straight line. All the carriages were started simultaneously. The dots indicate similar intervals of time (about half seconds). These were produced by the swinging of a pendulum across a cup of mercury and electric connections with the various receivers. The ground in which the above vibrations were produced was a hardened mud.

EXAMPLES OF RECORDS

I



II



III