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ART. VIII.—*Seismoscopes and Seismological Investigations*; by T. C. MENDENHALL.*

SEISMOLOGY as a science, or at least as an observational and experimental science, may be said to be the product of the past three or four decades. It is true that before as well as during this period some important applications of the statistical method of investigation were made and the distribution of earthquakes in time and space was thoroughly studied. These investigations are of really high value, although they have generally resulted in the overthrow of certain hypotheses which were constantly appearing as to the correlation of these displays of seismic energy with other natural phenomena; so that while it may be said that little is yet known concerning the real nature and origin of earthquakes, much useful work has been done in the way of elimination and possibly a reduction of the number of unknown quantities involved.

The new phase which the science has assumed may perhaps be fitly described by saying that the modern seismologist studies an earthquake, rather than earthquakes. In fact this is one of a considerable group of problems primarily geological in their nature to which, in recent years dynamical principles and physical methods have been applied. The knowledge of first im-

* Read at the meeting of the National Academy of Sciences at New York Nov. 8th, 1887.

portance in regard to an earthquake is the knowledge of the nature and location of its origin and it is generally admitted that this can be obtained only through the study of individual instances. The natural method is to proceed from the known effect to the unknown cause, and for a time progress in seismology consisted largely in painstaking and laborious investigations of the destructive effects of earthquakes from which it was believed a knowledge of their ultimate origin might be deduced. Little in the way of experiment had been attempted and nothing was known of the really complex motion of the earth-particle when subjected to the influence of an earthquake wave. False assumptions were made with regard to this motion and erroneous and perplexing conclusions resulted. The great work of Mallet on the Neapolitan Earthquake, although of much importance in its day, and always a monument to his industry and devotion to the science, can not now be considered as of any great value as a solution of the problems involved.

The importance of earthquake measurements by means of specially constructed instruments was recognized by Mallet, however, and he undertook the design and construction of such instruments at an early date. The problem seemed at first easy, but investigation proved it to be of considerable difficulty. In a general review of the state of the science in his report to the British Association in 1858 Mallet says,* "twelve years ago the construction of seismometric instruments appeared a comparatively easy matter. It is only at a very recent period that experiments and observations as to the actual phenomena, the velocity and direction of the shock, etc., have begun to show the real difficulties of the subject." But even at this time Mallet failed to recognize the true nature of the disturbance produced by an earthquake, and the several seismometers which he devised, and which will be found described in the report already referred to, are practically of no value. One of them, which was extremely elaborate in its construction, he considered competent to furnish, from a single station, all of the elements necessary for the determination of the seismic focus. Another, the arrangement of two rows of cylinders of varying diameters in lines at right angles to each other, is probably the most widely known of all earthquake machines as it is described in many encyclopædic articles and treatises on Geology in which the subject is discussed. It may be said, however, that a more useless device has never been proposed.

A notable advance in our knowledge of the subject and particularly of instrumental Seismology has been made during the last half dozen years and it must be largely attributed to the

* On the Facts and Theory of Earthquake Phenomena—Report of the British Association, 1858.

organization and active operations of the Seismological Society of Japan. Earthquakes are there so frequent that a rare opportunity for their study is offered. A few foreigners temporarily residing in the country, together with a number of native scholars, joined in the prosecution of seismic investigations and in the establishment of the Society. Its published transactions, already filling ten volumes, contain nearly all of seismology that is in advance of the old methods. Progress has been made mostly in the direction of improvement in seismographs, and is, in a great degree, due to better methods for securing the very desirable "steady point" and to a recognition of correct dynamical principles in the construction of the instruments.

The well known horizontal pendulum or "bracket" seismographs of Ewing,* Gray,† Milne and others, have greatly increased our facilities for research and, in fact, have afforded about the only fairly reliable information concerning the real movement of the earth-particle.

Notwithstanding the comparative infrequency of earthquakes in the United States, many advantages for their study are offered here. Among others may be mentioned the following: the great extent of country which could be brought under one system of observations;—a generally intelligent population, furnishing a corps of willing and reliable observers;—the extensive system of telegraph lines; and, perhaps superior to every other, the wide distribution and almost universal use of "standard time" throughout the country. In consideration of these advantages and of the fact that certain portions of the country appear to be subject to occasional seismic disturbances, it has seemed desirable that an extended and well planned series of observations should be undertaken, and that seismology should not be in the future, as it has been in the past, a somewhat neglected science.

Among American geologists especially, there has always been great interest in the subject, and a good deal has been written concerning geological theories of earthquakes. Rockwood‡ has done excellent service in his publication of frequent catalogues of earthquakes in America, together with such information regarding them as could be incidentally gathered. But the first important step towards an elaborate and systematic study of earthquakes was taken a few years ago by the Director of the U. S. Geological Survey in establishing what has been known as the "Earthquake Commission." The work of this body, during its existence, consisted mainly in the discussion of methods of observation, together with the preliminary arrange-

* Trans. Seis. Society of Japan, vol. ii.
† Trans. Seis. Society of Japan, vol. iii.
‡ This Journal, from 1872 to the present time.

ment of a plan of attack and the selection of the most desirable regions for the inauguration of the work. A scale of intensities was adopted and a series of questions formulated which were printed in the form of circulars for distribution among the intelligent observers of any disturbance. These circulars were subsequently made use of by Captain Dutton, who had the general direction of the work, and considerable information concerning several earthquakes has been obtained. The Charleston earthquake of 1886, renewed and greatly increased the interest in the problem. It was thoroughly investigated by Dutton and Hayden and their report* upon it, presented to the National Academy of Sciences in April, 1887, is of great value. As complete, perhaps, as was possible under the circumstances, it serves to emphasize the necessity for the use of seismic apparatus, and causes extreme regret that instruments had not been previously perfected and put in operation.

I think it can be said that America has made at least one really valuable contribution to the Science of Seismology. I refer to the approximate determination of the velocity with which earthquake waves are transmitted through the crust of the earth. The unexampled opportunities offered in the explosions at Hell Gate and Flood Rock† were utilized for this purpose, with the unexpected and surprising result of a rate of transmission vastly greater than that previously obtained by European and Oriental Seismologists, and generally accepted as fairly accurate. The reduction of fairly accurate time observations made on the occasion of the Charleston Earthquake,‡ served to confirm this conclusion and a speed of several thousands instead of a few hundreds of meters per second must now be admitted. Although these results are more nearly in accord with the theory of wave transmission, future determinations of velocity will be awaited with great interest, and all processes employed must be carefully scrutinized.

Before considering a plan for the inauguration and maintenance of an extensive series of seisomological observations, it will be well to inquire what knowledge is most desirable in the interests of geological investigation. This is a question for geologists to answer; but I venture the assertion that in the present state of our knowledge of seismology, it is most desirable, in the case of any given earthquake, to be able to fix the seismic vertical, or the epicentrum; to ascertain the depth at which the initial disturbance occurred; and to measure the velocity with which the resulting waves are transmitted. If these can be accurately determined for different earthquakes, under varying conditions, some light may be

* Science, May 20th, 1887. † Science, Jan. 8th, 1886.
‡ Science, May 20th, 1887; see also this Journal, Jan., 1888, pp. 1–15.

thrown upon their ultimate origin and the magnitude of the energy involved, while the study of velocities of transmission, co-seismal and iso-seismal lines, may afford valuable information concerning the nature and condition of the rocks within the disturbed area. Admitting the greater importance of a knowledge of these facts it follows that time measurements should first receive attention, and that the seismic chronograph is the instrument to be used.

The seismograph or seismometer is designed primarily for the purpose of recording or measuring the actual motion of that part of the earth to which the instrument is attached during the transit of one or many waves. In reality this motion is extremely complex. Undoubtedly the emerging wave is modified very greatly in its character by the lack of homogeneity in the material through which it last travels, as well as by the fact that this material differs immensely in elasticity and density from that in which it has in the main existed. For this reason it is believed that however accurately the motion may be resolved into three components at right angles to each other by a perfectly operating seismograph, but little information would be afforded as to the position of the origin, or the amplitude of vibration and amount of acceleration of any point in the earth, other than that at which the instrument is located. It is clear, however, that while these considerations may seriously affect the integrity of the record of a seismograph, they will have little influence upon the actual transmissive time, that is to say, while the character of a wave may be greatly altered upon emergence into a non-compacted, non-homogeneous material, the time of its arrival at a given point cannot be greatly altered, even if its velocity in this material is much less or greater than the mean, for the reason that it is subjected to this modifying influence for a comparatively brief period. It is true that the seismograph, in addition to registering the motion of the earth particle, may and generally does record the epoch of the passage of a wave, and it affords the advantage of distinguishing one wave from another. If only very short distances are used for the determination of velocities this would be of decided value, were it not that experience* seems to prove that what is the maximum wave at one point may not be the maximum at other points very near, so that it is by no means certain that a particular wave can be identified at different stations, even if they are not widely separated. These considerations, together with the very great expense of seismographic equipment and the greater difficulty of maintaining them in constant working order in a country where earthquakes are infrequent, compel the admission that

* Milne, in Trans. Seis. Soc. of Japan, vol. x.

the simple seismoscope, with a time-taking attachment, is far more likely to furnish valuable information.

SEISMOSCOPES.

A good seismoscope should possess some if not all of the following characteristics:—

It should be simple, inexpensive and not liable to become inoperative through long periods of rest;

It should be capable of adjustment to varying degrees of sensitiveness;

The adjustment of different instruments to nearly the same degree of sensitiveness should be possible;

Its equilibrium should be unstable; that is, when once disturbed it should not "reset" itself;

It should not be liable to register phenomena other than actual movements of the earth upon which it rests.

While much has been done and notable advances have been made in the construction of seismographs with a view to the determination of the character of the motion of the earth particle, it does not appear that a seismoscope satisfying these conditions has yet been described or extensively used, although an infinite variety of instruments bearing the name have been devised. If whatever is done in the near future is likely to be done through the use of the time-registering apparatus, and this, I believe, is the opinion of the majority of the members of the earthquake Commission assembled upon the invitation of the Director of the Geological Survey, the subject becomes one of considerable importance, and a recognition of this fact has resulted in the suggestion of several new forms of seismoscopes within the last two or three years, a few of which have been actually constructed and tested. The first of them, and the only one as far as I know which has been used to register the occurrence of an earthquake in this country, was designed in the Physical Laboratory of the Signal Office at Washington. While others contributed suggestions as to certain details, the general form of the instrument is due to Junior Professor C. F. Marvin, of the office of the Chief Signal Officer.*

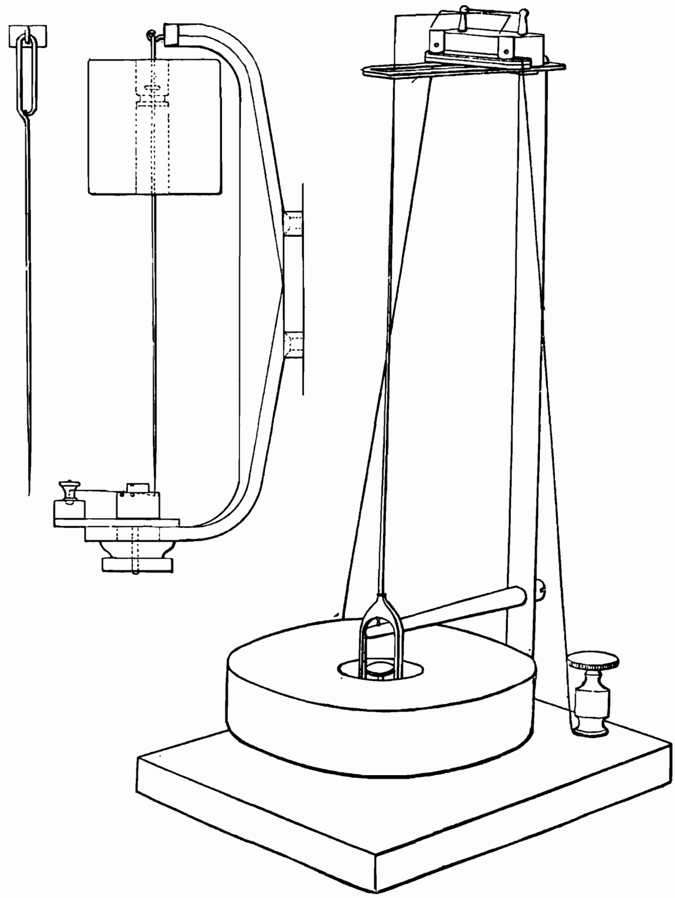
It is shown in figure 1 and a little explanation will make its operation clear.

An iron cylinder weighing three or four pounds has a cylindrical hole of about 2^{cm} in diameter, bored through concentric with its axis. At a point a little distant from the

*The first practical use of an instrument of this type was at the Flood Rock Explosion in October, 1885. It was placed by direction of the writer at the nearest point of observation, on Ward's Island. Its performance was entirely satisfactory. See Science, Oct. 16, 1885. An instrument somewhat similar in design with a very imperfect contact-making device was suggested by Milne. See Trans. Seis. Soc. Japan, vol. iii.

center of gravity this hole is suddenly diminished in diameter by a small amount, affording a shoulder against which rests a cross piece filling symmetrically only a part of the opening and carrying at its center, which is on the axis of the cylinder, a fine steel point. This point rests in a small depression on the inner side of a link, to which is attached a long steel needle as

1. 2.



shown in the cut. The upper end of the link hangs upon a hook made of wire of the same diameter and rigidly attached to the supporting frame of the instrument which is of iron. By this arrangement for the suspension of the heavy mass, the link with its needle projecting downwards, has considerable freedom of motion in all azimuths, with little frictional resistance, and for slight movements the pivotal point within the cylinder may be regarded as fixed. Rotation takes place about this point and the motion of the earth, which is that of the hook upon which the link is suspended, is magnified at the point of the needle as many times as the ratio of the length of the needle to that of the link. A small and very light lever has its short arm bent upward, and is so adjusted that when the instrument is "set," the upper end, ground to a fine point, rests against the pointed end of the long needle. The longer and heavier arm of this lever terminates in a platinum fork, the prongs of which are vertically above two small mercury cups forming terminals of the electric circuit.

The operation of the instrument is simple. A very slight movement of the point of suspension is magnified at the needle point; the short arm of the lever is released and the fork drops, closing the circuit. Different degrees of sensitiveness are obtained by grinding the abutting points to greater or less dimensions.

A seismoscope of great simplicity of design, and offering many advantages, is one originally due to Milne,* and more recently with slight modifications, experimented with by Hayden and Hallock, of the U. S. Geological Survey, by whom it was also, I believe, independently invented. It belongs to the family of liquid seismoscopes, of which many varieties have appeared, notably several devised and used by Palmieri. In all previous forms, however, the action utilized was the movement of the whole mass of liquid in relation to the containing vessel, while in this, advantage is taken of the well known fact that waves are, in general, produced upon the surface of a mass of liquid when it is subjected to a sudden disturbance. In a cylindrical vessel these waves run from circumference to center, at which point the liquid is sensibly elevated for an instant, and through this elevation an electric circuit may be momentarily closed. Mercury is the liquid used, and it is placed in a small cylindrical iron box, through the cover of which a pointed screw with a large divided head runs. The point of the screw, which is of platinum, may be brought extremely near the surface of the mercury, its position and distance being known by means of the divisions on the head. A slight jar generates a series of waves, the elevation at the center completes the circuit through the properly insulated screw. The tendency of the mercury to become oxidized or dirty upon the surface so as to become inoperative was overcome by the use of a small platinum float, a device previously employed for measuring the height of the mercury in the cistern of a barometer by electrical contact. A

* Trans. Seis. Soc. Japan, vol. iii.

simple arrangement for keeping this float in position is employed and the real contact is between two platinum surfaces, being thus much more desirable and lasting.

Several other forms of seismoscopes have been suggested and tried with more or less success. One of these is a modification of the well known Zöllner's horizontal pendulum, the extreme sensitiveness to change in level of which has been so well shown by Professor Rood.* It is easy to arrange this so that an electric circuit is closed when a disturbance occurs; and, although its greatest sensitiveness is for disturbance in one plane it is generally sufficiently delicate to respond to very feeble motions in all azimuths.

I have recently modified the instrument first described, reducing its dimensions and cost, and greatly increasing the ease with which it is adjusted and "set." The alteration consists principally in extending the multiplying needle upward instead of downward. This brings the circuit-closing part of the apparatus above, where it is open to inspection and convenient for adjustment. The supporting frame rests upon a square or triangular base, and can be placed upon any convenient pier or table, instead of necessarily being screwed to a vertical support as in the earlier form. The latter plan was adopted with a view to fastening the instrument to a post driven in the earth, but it has been found inconvenient in practice, and it will generally be better to rest it upon the top of the post, if one is used, or upon a stone imbedded in the earth, or upon a bracket shelf attached to a foundation wall.

The new form of the instrument is conveniently covered by an ordinary glass shade to protect it from dust and disturbance by air currents. An improvement is made in the arrangement for adjusting the position of the circuit closer, which is held to the table upon which it rests by means of a spiral spring, so that while it moves freely upon the application of a slight pressure it is sufficiently firm to resist accidental disturbances. The new form will be readily understood by examination of fig. 2 (p. 103.)

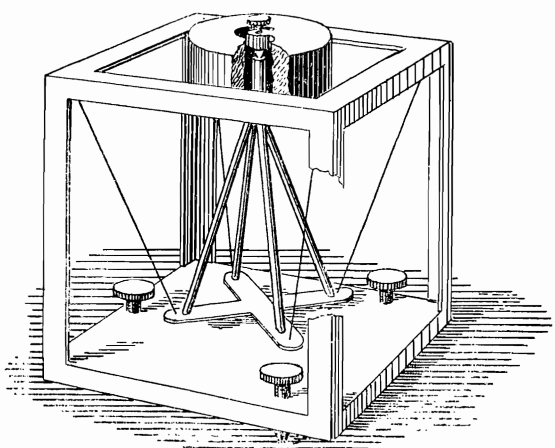
Any mechanical device by means of which a temporarily "steady point" is provided may be utilized as a seismoscope. The horizontal pendulum, first suggested by Chaplin and utilized by Ewing in his seismograph, satisfies the requirements, except that its sensitiveness exists in only one plane. The use of some form of link motion for an astatic suspension was suggested by Professor West a few years ago, at a meeting of the Seismological Society of Japan.† It is clear that an ideal arrangement would be the Peaucellier linkage for straight line motion in a horizontal plane. But it is difficult if not impossible to avoid

* This Journal, III, June, 1875.

† Trans. Seis. Soc. Japan, vol. vi.

an amount of friction which would be fatal. Ewing * has suggested the use of some form of linkage in which only ties should be used, so that flexible cords could be substituted for rigid bars. No rigorously straight-line motion is susceptible of this construction, but several close approximations may be utilized. An approximation is all that is required in a seismoscope, but it must possess freedom of motion in all azimuths. Professor Ames, of the Rose Polytechnic Institute, has devised a form consisting of a combination of two linkages of the form invented by Roberts. By arranging these in planes at right angles to each other, freedom of motion in any azimuth is secured. A heavy mass is pivoted at the tracing point and friction may be reduced to a minimum by the use of flexible cords, fine wires or by pivoting light rigid links. The suspension is approximately astatic, but sufficiently so for seismoscopic uses, and perhaps for seismographs—It is shown in figure 3.

3.



A number of trials with several of these seismoscopes under different varieties of disturbance show that all are not equally sensitive to the same disturbance, however delicately they may be adjusted. The mercury seismoscope is peculiarly sensitive to disturbances produced by a slight jar of the table or support upon which it rests. In this case the vibrations are generally very rapid, probably from ten to fifty or more per second. It may readily be adjusted to respond to extremely slight tremors and besides it apparently affords the advantage of being set at any time to a definite degree of sensitiveness. With the two

* Memoirs of the Science Dept., Tokyo Daigaku, No. 9.

or three instruments of this class upon which I have experimented, this theoretical advantage is not realized in practice. The distance between the two platinum surfaces is so extremely small, when the instrument is sensitively adjusted, that very trifling and generally unknown causes will considerably modify the position of the divided head when contact occurs. The setting of the instrument is therefore a matter of great uncertainty.

This instrument possesses what at first appears to be an advantage, in that it is "self-setting;" but a reference to what has gone before will show that this is not considered a desirable feature of a seismoscope. In fact, it is very undesirable in my judgment, except where devices of a special character are made use of for securing time records. If the epoch is established by stopping or starting a clock or by Milne's printing device, a self-setting instrument would be objectionable. If the record is made upon the revolving drum of a chronograph, or on a continuously moving strip of paper, this form of seismoscope might fix the time of all sensible movements during the disturbance, and might, indeed, play the part of a seismometer in some degree by distinguishing the more violent motions. But it would be likely to fail in this respect, as well as in its general performance as a seismoscope, owing to the peculiarity already referred to. To vibrations of moderately long period it does not promptly respond. Earthquakes seldom, if ever, begin with a sharp and sudden movement. The maximum vibration is nearly always preceded by several of less amplitude and nearly the same period, which are themselves preceded by oscillations of extremely small amplitude but of great frequency. The intensity of these preliminary tremors is not, in general, sufficient to cause a mercury seismoscope to act, and to the succeeding movements of greater amplitude but longer period, (often as long as one second) it is not sensitive. Further experiment and investigation is needed, however, to determine the relative merits of these and other instruments.

Time Apparatus.

Various methods of time-registration have been made use of, and most of them are generally well known. A choice among them must depend largely on the probable frequency of earthquake phenomena. In Japan and some other parts of the world rarely more than a few days pass without a sensible disturbance.

A continuously operating chronograph would be desirable and profitable under such circumstances and various modifications of the ordinary astronomical chronograph will at once suggest themselves as suitable for this work. When an earthquake is a rare phenomenon, years instead of days elapsing between two successive disturbances, all appliances for their observation must be of the utmost simplicity of construction consistent with certainty and accuracy of performance. A fairly good clock is a necessity and that being provided it remains to determine how it may be used in recording the instant of disturbance. One of three different schemes may be adopted: a running clock may be stopped; a clock at rest with hands set in a known position may be started, or the position of the hands may be registered without interfering with the going of the clock. Either of these can be easily accomplished through the instrumentality of the electric circuit closed by the effect of the disturbance on the seismoscope. The simplest method is that of stopping or starting the clock, and considerable difference of opinion has existed as to the relative merits of these two processes. It will be seen at once that the plan of starting a clock from rest in a known position would have many advantages, and one of them is certainly of great importance. It is that after the happening of the earthquake the started clock can be allowed to run until a comparison with some standard time is possible and if necessary its rate may be determined, so that the exact epoch of the disturbance can be ascertained with considerable accuracy. On the other hand, if a clock be stopped our knowledge of the exact time of the occurrence will depend on our knowledge of its error at the time of stopping, which can only be known through previous observations of error and clock rate. Thus it will appear that if the method of clock stopping is to be resorted to, the clock must be under constant surveillance and frequent comparisons must be made with some standard time. The clock-starting method is also open to some rather serious objections. A clock which has been at rest for months or even years is hardly likely to be constant in its rate during the first few hours after starting. This objection can be in a great degree removed, however, by carrying out suggestions to be given later. Another, and more important, is that the record is liable to be lost entirely through the subsequent stopping of the clock by the violence of the earthquake. The clock-stopping method is not open to this objection as it is difficult to imagine the starting of a clock by an earthquake, particularly if the pendulum is held somewhat firmly by the stopping apparatus. The third plan, that of registering the position of the hands of the clock at the moment of closing the circuit without interfering in any way with the movement of the clock combines many of the advantages of both the others, but has the disadvantage of being more complicated and difficult to accomplish. It is easy to expose for an instant a quick photographic plate, upon which an image of the clock face is projected, but we at once meet with the difficulty of properly illuminating the face at night.

Among other methods which have been proposed, probably the most simple is that of Milne,* which consists in placing small pieces of cork, coated with an oily ink, upon the extremities of the hands of the clock against which a paper or card board ring is pressed by electro-mechanical devices, put in operation by the closing of the circuit at the seismoscope. After an instant of pressure the ring is withdrawn, bearing a printed record of the position of the hands of the clock. This allows the determination of the error and rate of the clock either before or after the earthquake or both, and should the clock be stopped by a violent shock, the time record is not lost. These advantages will undoubtedly lead to the invention of simple and sure methods by means of which this printed record may be obtained. For stopping a clock, Milne† has used a thin piece of board in which notches are cut in one of which the pendulum is caught at the moment of the disturbance. This method is likely to allow and sometimes to cause considerable subsequent swaying of the pendulum and I have preferred to use simply a strip of brass, curved to an arc of the circle whose radius is the pendulum. This lies always nearly touching the pendulum and is slightly lifted when the circuit is closed so as to arrest the pendulum. The brass strip is attached to the movable armature of a common telegraph sounder secured to the side of the clock case. The circuit remaining closed after the action of the seismoscope the pendulum is held in its place.

Application.

Two seismic stations with time-taking apparatus have been in operation in this country for nearly a year. The first was established in the Physical Laboratory of the Signal Office in Washington shortly after the occurrence of the Charleston Earthquake, and the second, at the Rose Polytechnic Institute, Terre Haute, Ind., was put in operation in January, 1887. Both are equipped with seismoscopes similar to that described and shown in fig. 1 and with clocks known as "Regulator No. 2," made by the Seth Thomas Co. These clocks were selected on account of their cheapness and their really excellent performance as time keepers. The stopping apparatus is of the simple form already described, and an ordinary vibrating electric bell with battery is connected with it so that a continuous alarm is maintained from the time of the disturbance of the seismoscope.

* Trans. Seis. Soc. Japan, vol. iv.

† Trans. Seis. Soc. Japan, vol. iii.

Since their installation these instruments have recorded as follows:—

At WASHINGTON.—From Oct. 6th, 1886, to Nov. 4th, 1887.

Date.	Time, (75th Mer.) h.	m.	sec.	Remarks.
October 22, 1886	2	46	14 p. m.	Felt generally in the vicinity.
November 5, 1886	12	27	14 p. m.	
February 23, 1887	7	33	0 a. m.	Possibly related to the great Italian earthquake of that time. From the condition of the instrument before and after the time of the record it was thought to be reasonably certain that it was due to a true seismic disturbance.

At TERRE HAUTE.—From Jan. 18th, to Oct. 26th, 1887.

Date.	Time, 90th Mer. h.	m.	sec.	Remarks.
February 3d	10	27	35 a. m.	Shocks in Italy, Feb. 3.
February 6th	4	15	6 a. m.	Shocks in Ind., Ill., Ky., and Mo.
February 10th	11	22	27 a. m.	Papers reported shock at Jasper, Ind., but not verified.
May 6th	7	45	22 a. m.	May 3d and 4th, general in Mexico and from Texas to Cal. 150 lives lost at Bahispe in Sonora, Mex., also many topographical changes.
May 10th	6	1	34 p. m.	Shocks in mountains daily, May 12 and 13, shocks in S. C., Cal. and Arizona, May 19 and 20 in Europe. May 30 and 31, in Mexico.
May 24th	10	3	33 a. m.	Shocks felt in Ind., Ill., Ky., and Tenn., and in Equador, S. A.
August 2d	12	35	43 a. m.	
October 22d	6	6	35 a. m.	

PLAN OF CAMPAIGN.

In determining upon a systematic plan for the instrumental study of earthquake phenomena, some consideration of the foregoing remarks seems to be demanded, and some useful conclusions may be drawn from the brief experience already had.

In the first place, it is claimed that time observations are of the first importance and that under the circumstances such only should be undertaken. It is believed that the reasons briefly, and in some degree imperfectly, presented in the foregoing discussion, are sufficient to establish the claim. Seismoscopes, with the accompanying clocks, should be the only instrument used, and these should be, as far as possible, of the same type. Before the adoption of any one of several different species available, a careful study of them should be made, all being tested under similar conditions and these conditions should resemble as closely as possible those under which the instrument is expected to work. As seismic phenomena are here too infrequent to admit of such preliminary test or calibration, means must be provided for imitating at will the motion of a point upon the surface of the êarth. Such an arrangement would also be useful in testing seismographs and the validity of their records.

For this purpose what may be called a " seismic table " has been designed. It consists essentially of a horizontal surface, large enough to furnish room for two or three seismoscopes or seismographs, and which by suitable mechanism may be given a vibratory motion in either one or all of three directions at right angles to each other, two of these motions being in a horizontal plane. The vibrations are all derived from a single piece rotating with a uniform angular velocity, and all are on a close approximation to simple harmonic motion. By a simple device their amplitude may be varied at will and without arresting the movement, from zero to a prescribed limit. Another mechanism enables the operator to vary the frequency of vibration from zero to any desired number per second. The machine is to rest upon a solid foundation and power is to be drawn from a steam or gas engine. At any moment, the amplitude and frequency of vibrations along any of the three components will be shown by suitably arranged indices. The disturbance to which a seismoscope is subjected can generally be resolved into approximately simple harmonic motions along these axes, and as the period and amplitude of vibration for earthquakes of moderate intensity are now tolerably well-known, through the investigations of Japanese earthquakes by Ewing, Milne, Gray and Sekiya, it will be possible to reproduce their movements with considerable accuracy and with such variations as to intensity as to satisfy every demand in testing seismic instruments. In this way it can be determined to what particular species of vibration a seismoscope is sensitive; whether the same seismoscope can be repeatedly set to the same degree of sensitiveness, and whether several different instruments can be made to agree in this respect. In addition to its great value as affording a means of testing and comparing instruments, it is believed that such an apparatus may be useful in studying certain observed effects of earthquakes upon simple structures. By submitting small but dynamically similar models of such structures to differently compounded vibrations and studying the results, some light may be thrown upon the confusing and often contradictory phenomena of actual earthquakes.

Assuming that a satisfactory form of seismoscope has been selected by subjecting all proposed or submitted to the test of the seismic table, it is important to consider next their distribution and use. As it is very desirable that they should be as numerous as possible, and as the cost of the equipment of a station is of great practical moment, it may be stated that the whole outfit for a single station, including clock, seismoscope, battery and all, need not cost more than twenty-five dollars, and it is hoped that a sum considerably less than that amount may be found sufficient. In selecting stations it is of the utmost importance that the question of accurate time should be first considered. Standard time signals from one observatory or another are now distributed so generally over the whole country, that in any considerable town no difficulty will be found in determining the clock error and rate, provided that the apparatus is in the hands of a suitable person. It is likely that in many instances jewelers or watch makers, who receive time signals daily will be willing to undertake the care of a seismic station. The seismoscope may be mounted upon a bracket secured to the stone or brick foundation of a building, in the cellar or basement, while the clock should be placed where it will be often seen, or where it may be of real service as a time-keeper to the observer. The use of an electric alarm, while not a necessity, is very desirable, as through its action attention is immediately called to the disturbance, and even a second or two of warning might enable many interesting observations of phenomena which would otherwise escape the observer.

I have found it very useful to provide for regular tests of the apparatus on the first of each month. An artificial disturbance near the seismoscope takes the place of a real earthquake and the operation of the bell-ringing, clock-stopping apparatus is observed, the clock error and rate applied, and in fact everything is done as if a real earthquake had occurred. This will enable the observer to detect any fault in his arrangements and will serve in a great degree to maintain his interest and sustain his patience through months or years of waiting for an actual record. Blanks should be furnished on which the results of these tests may be recorded and forwarded to the person in charge of the whole system of observations. Many other details might be referred to, but they belong rather to a code of instructions for observers. There is one matter connected with the establishment of stations, however, which experience has shown to be important.

The records of a seismic station, even when equipped in the best possible manner, will be unquestionably affected by what may be called "accidental errors." That is to say, it is believed that the best of seismoscopes will fail to satisfy entirely the conditions given above and will occasionally "go off" when there has been no real seismic disturbance. This may be due to a variety of causes, among which may be mentioned: changes in the position, level, etc., of the support of the instrument, through a slow movement of the wall or pier to which it may be attached; occasional movement of heavy bodies in close proximity to the instrument; very violent winds which may disturb the foundation of the building in which it is placed, etc. It is often difficult to distinguish a false alarm thus given from a true seismic disturbance and in the records of the seismoscopes at Washington and Terre Haute already given, two or three doubtful instances occur.

When the earthquake is sufficiently violent to be detected without instrumental aid, confirmatory evidence is furnished; but one of the principal objects in making use of instruments is to detect movements which would otherwise pass unnoticed and to extend the range of observation of the more violent far beyond what it can be at present. As an illustration of the great importance of being able to know a genuine record I may invite attention to one of the records made at Washington a few hours later than the Italian earthquake of last year. The epoch of the disturbance is such that there is nothing unreasonable in supposing that it was really a wave which had been transmitted across the sea or through the crust of the earth. Interesting as this fact would be, it would be rash to make such an assumption in view of the possibility of a purely accidental disturbance of the instrument.

A very similar state of affairs exists in connection with one of the records of the Terre Haute seismoscope. Had there been several instruments along the Atlantic coast they might have confirmed or confuted the record made at Washington. It is highly probable, however, that disturbances frequently occur which do not affect large areas. In arranging for the systematic observation of phenomena so rare and so uncertain as to time and place as earthquakes, it will hardly be possible to place stations sufficiently near each other to insure the detection of these minor movements, although they are for many reasons of prime importance. With the possibility of accidental disturbance and with seismoscopes somewhat widely separated, it would seem impossible ever to certainly detect such minor movements in the surface of the earth. There is a remedy, however, and it lies in the precaution, the truth of which experience has forced upon me, that *wherever there is one seismoscope there must be two.* That is to say, when any locality is selected as a suitable place for a seismic station two complete stations must be established, separated sufficiently so as not to be liable to the same accidental disturbances but near enough to render it reasonably certain that a real seismic disturbance which affects one will also affect the other. If separated by a distance of from a few hundred feet to a quarter or half a mile, the necessary conditions would be satisfied. Two such stations ought to sensibly agree as to the exact time of any disturbance and not only would they enable the observers to distinguish accidental or false alarms, but they would afford excellent checks upon each other on the occasion of a genuine record.

It is hardly necessary to refer to the interesting and important results which would almost certainly come from the organization of one hundred or even fifty such stations wisely distributed, at first over those sections of the country known to be most subjected to earthquakes. On the hypothesis of transmission through a homogeneous, elastic medium, records at less than a half dozen stations will suffice to determine the velocity of transmission, and the coördinates of the origin of the disturbance. Although in the case of the earth this hypothesis is not tenable, it is an approximation to the truth, and there can be no doubt that the mean of a number of such determinations, based upon different groups of observations would have considerable weight in the discussion of the dynamics of the problem.

I think it will be generally admitted that the management and direction of an investigation so extensive as the territory involved could only be successfully carried out by the government; and that the Director of the Geological Survey, of whose disposition in the matter there can be no doubt, should be furnished by Congress with the authority and material for its accomplishment.