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SELECTION INSTALLATION AND OPERATION OF SEISMOGRAPHS

By

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U.S. COAST & GEODETIC SURVEY
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SELECTION, INSTALLATION, AND OPERATION OF SEISMOGRAPHS

PURPOSE OF THE STATION

1. In establishing a seismograph station and in selecting the instruments with which the station is to be equipped, consideration should be given to the purpose for which resulting records are to be used, the possibility of continuous operation over a long period of time, and the extent to which cooperation with other institutions or organizations is contemplated.

Seismograph stations may be divided into three general classes, (*a*) those which are intended only for the registration of distant earthquakes, (*b*) those which are established in seismic regions for the study of feeble shocks which may occur very frequently in the region, and (*c*) those which are distributed over areas in which destructive earthquakes are most likely to occur. (Instruments used in seismic prospecting will not be described in this paper.)

The instruments in common use at stations of the first two classes require daily supervision as they are usually in operation continuously, but those in the third class, which are intended for registration of strong seismic motion, usually operate automatically at the time of a severe or destructive earthquake in the immediate vicinity of the instrument.

THE REGISTRATION OF SEISMIC WAVES

2. It is generally believed that earthquakes are caused by the sudden relief of accumulated stresses in the earth's crust. Whether the resulting movements of the ground are associated with volcanic disturbances or are the result of readjustments along new or old fault planes, much of the energy which is released, appears in the form of seismic waves which are propagated in all directions through the earth and along its surface. The seismograph is an instrument which is designed for the detection and registration of these seismic waves and when properly constructed and operated it furnishes a permanent record of such waves. The records, known as seismograms, may be of general scientific interest in connection with studies relating to the interior of the earth or to crustal structure and also may be of great economic value in the evaluation of ground movements associated with destructive earthquakes.

A few seismograms, as recorded by different instruments at different stations are shown in the accompanying illustrations. Some of the more prominent waves or "phases", as they are generally called, have been marked on the grams. Seismologists recognize different types of waves, many of which have been reflected or refracted at

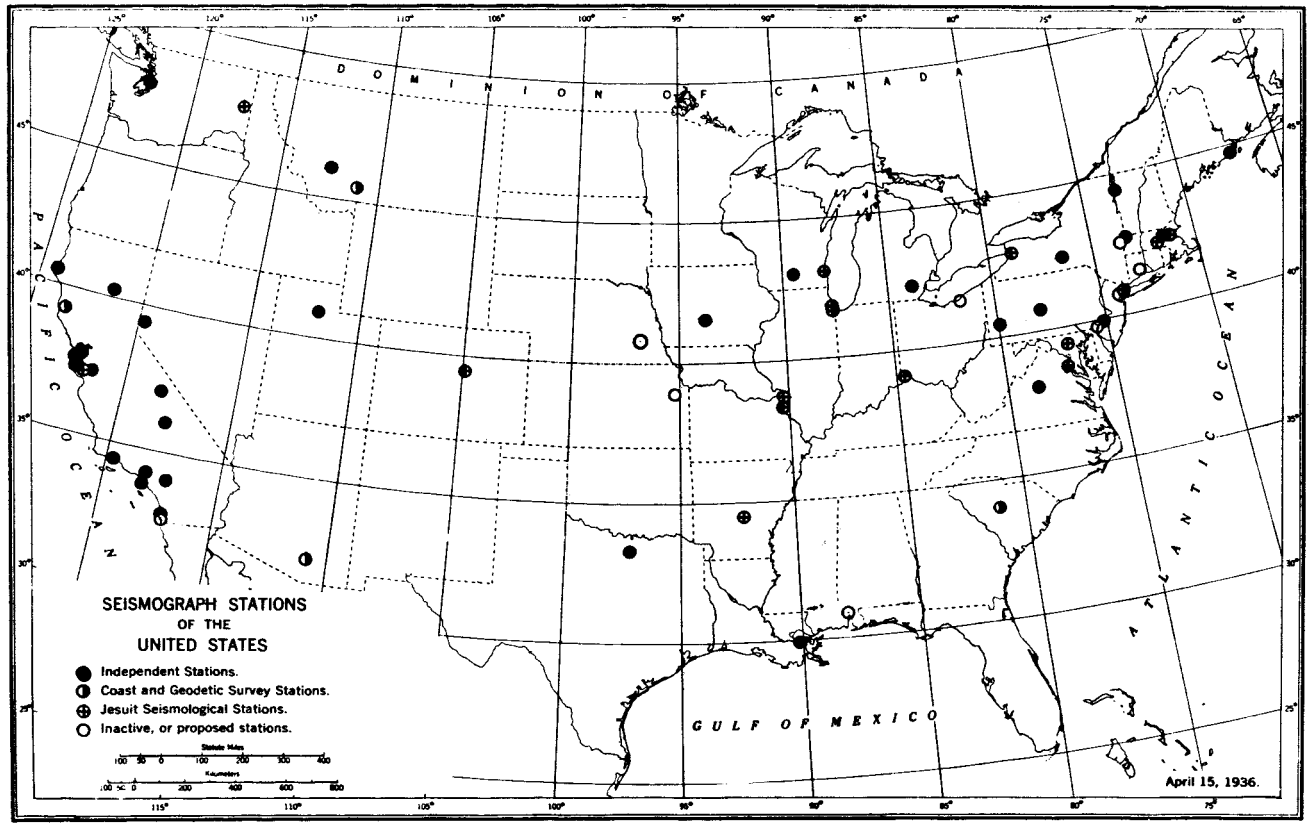

FIGURE 1.—Seismograph stations of the United States.

surfaces of discontinuity within the earth. Seismic waves are propagated with different velocities depending upon their mode of vibra-

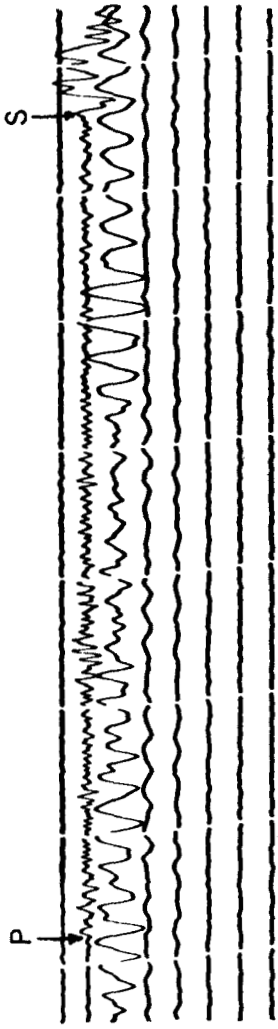

FIGURE 2.—Record of the Grand Banks earthquake made by E-W component Wood-Anderson seismograph at Tucson magnetic observatory, Tucson, Ariz., on November 18, 1929.

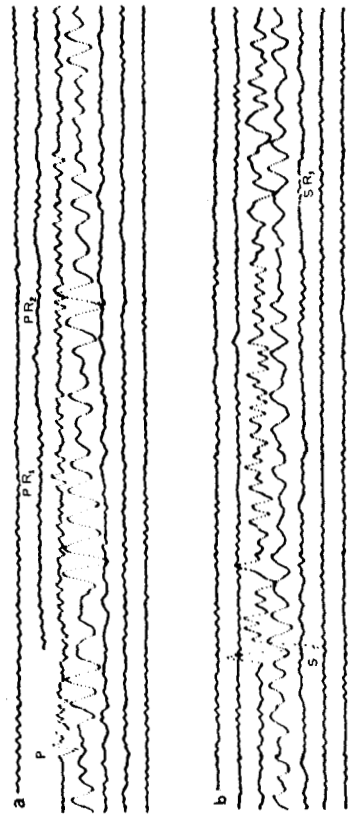

FIGURE 3.—Seismogram recorded by a Wenner horizontal component seismograph at the National Bureau of Standards, Washington, D. C.

tion and the character of the medium through which they travel. In the first preliminary group (P waves), the vibration of the earth

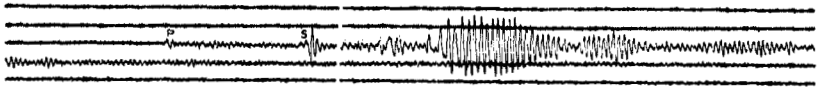

FIGURE 4.—Section of seismogram recorded by a Milne-Shaw seismograph near Honolulu, March 22, 1925. Epicenter in the New Hebrides. Distance about 5,500 kilometers.

particle is longitudinal, that is, in the direction of propagation. In the secondary (S wave), the plane of vibration is at right angles to the line of progress. The P and S waves traverse the same path but

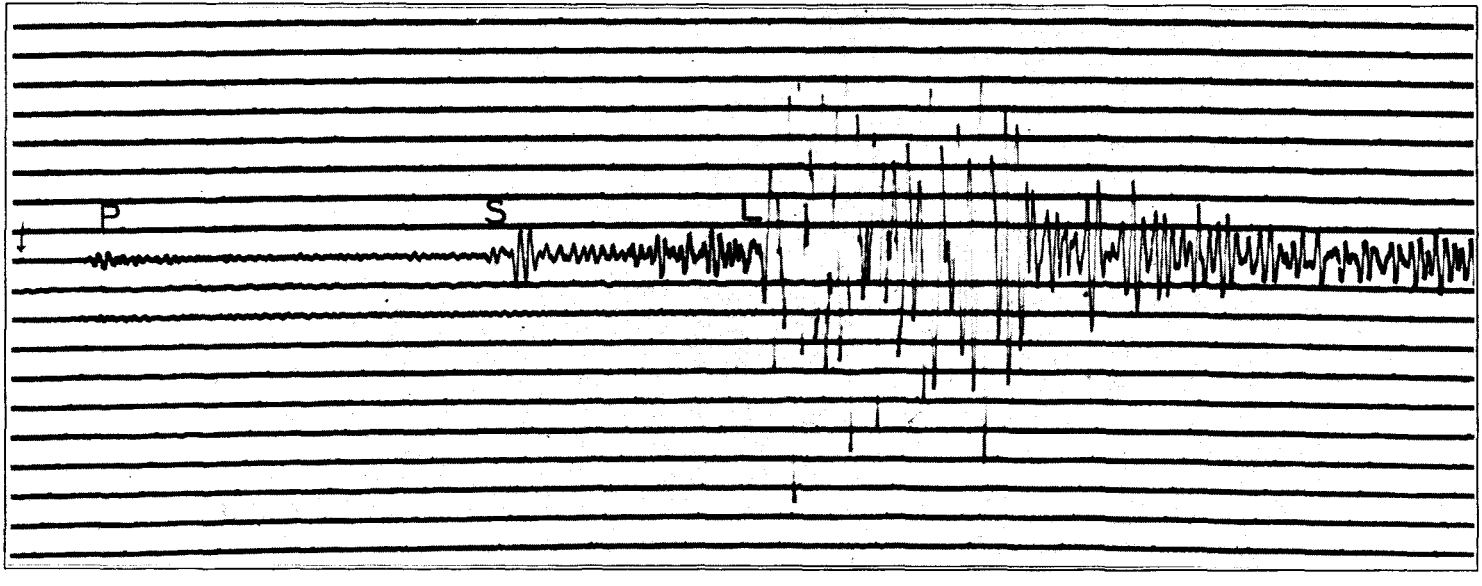

FIGURE 5.—Section of a seismogram recorded by a McComb-Romberg seismograph, small model, on August 16, 1931, at Washington, D. C. Component, N. 75° E. Time mark as indicated by arrow point was at 11^h 45.0^m Greenwich civil time. Epicenter 30.0° N.; 104.5° W.; southwestern Texas.

as their velocities differ they arrive at any station in succession. Traveling at a still slower speed and over a longer path, surface waves, usually called long waves or L waves, arrive later and in general are the most prominent portion of a seismogram. The difference in times of arrival of the different waves is a measure of the distance of the epicenter from the station and for this reason it is important that time marks be placed on the grams at sufficiently short intervals to insure reasonably accurate estimation of the times of beginnings of the different phases.[1] It is customary in teleseismic work to provide for time marks on the grams at intervals of 1 minute. Various methods are employed for production of these time marks but usually the mechanisms are operated electrically from accurate pendulum clocks keeping standard time.

As a result of individual and cooperative efforts, seismograph stations are now operated in all parts of the world. The teleseismic stations of the continental United States are shown in figure 1, and a full list, including those in outlying possessions, is given in table 1.[2] A list of Coast and Geodetic Survey stations devoted to the registration of strong seismic motion is given in table 2.

TABLE 1.—***Seismograph stations of the United States and outlying possessions***

EXPLANATION OF ABBREVIATIONS

* = *Station cooperating with United States Coast and Geodetic Survey.*
C. & G. S. = United States Coast and Geodetic Survey.
Cal.-Tech. = California Institute of Technology.
C. I. W. = Carnegie Institution of Washington. Seismological Laboratory at Pasadena.
J. S. A. = Jesuit Seismological Association.
U. S. N. P. S. = United States National Park Service.
U. S. W. B. = United States Weather Bureau.

Location	By whom operated
ALABAMA	
Silver Hill	Silver Hill College, near Mobile (Jesuit).
ALASKA	
College	University of Alaska and C. & G. S.
Sitka	Sitka Magnetic Observatory, C. & G. S.
ARIZONA	
Tucson	Tucson Magnetic Observatory, C. & G. S.
ARKANSAS	
Little Rock	Little Rock College (Jesuit).
CALIFORNIA	
*Berkeley	University of California.
Ferndale	J. Bognuda and University of California.
*LaJolla	C. I. W. and Cal.-Tech.
Mineral	U. S. N. P. S.
Mt. Hamilton	Lick Observatory—Seismograph Station, University of California.
*Mt. Wilson	C. I. W. and Cal.-Tech.
Palo Alto	Stanford University and University of California.
CALIFORNIA—contd.	
*Pasadena	C. I. W. and Cal.-Tech.
Point Loma	Theosophical University.
*Riverside	C. I. W. and Cal.-Tech.
Santa Barbara	C. I. W. and Cal.-Tech.
Santa Clara	Santa Clara University (Jesuit).
San Francisco	University of San Francisco and University of California.
*Ukiah	C. & G. S.
*Tinemaha	C. I. W. and Cal.-Tech.
*Haiwee	C. I. W. and Cal.-Tech.
CANAL ZONE	
Balboa Heights	Panama Canal.
COLORADO	
Denver	Regis College and J. S. A. (Jesuit).
CONNECTICUT	
New Haven	Yale University (inactive).
DISTRICT OF COLUMBIA	
*Georgetown	Georgetown University (Jesuit).

[1] Frank Neumann; Principles Underlying the Interpretation of Seismograms. Coast and Geodetic Survey.
[2] See also: List of Seismograph Stations of the World, by H. E. McComb and Clarence J. West.; Bul. Nat. Res. Council. no. 82. 1931.

TABLE 1.—*Seismograph stations of the United States and outlying possessions—Continued*

Location	By whom operated
GUAM	
Guam	Manila Observatory.
HAWAII	
Hilo	U. S. N. P. S.
Honolulu	University of Hawaii and C. & G. S.
Kona	U. S. N. P. S.
Volcano House	U. S. N. P. S.
ILLINOIS	
Chicago	Loyola University (Jesuit).
*Chicago	C. & G. S., U. S. W. B., and University of Chicago.
IOWA	
*Des Moines	Mrs. M. M. Seeburger (private station).
LOUISIANA	
New Orleans	Loyola University (Jesuit).
MAINE	
*Technology (near East Machias).	Massachusetts Institute of Technology.
MARYLAND	
Woodstock	Woodstock College (Jesuit).
MASSACHUSETTS	
*Harvard (Oak Ridge).	Harvard University.
Weston	Weston College (Jesuit).
Worcester	Holy Cross College (Jesuit).
Williamstown	Williams College.
MICHIGAN	
*Ann Arbor	University of Michigan.
MISSOURI	
Florissant	St. Louis University (Jesuit).
*St. Louis	St. Louis University (Jesuit).
MONTANA	
*Bozeman	Montana State College and C. & G. S.
Butte	Montana School of Mines, C. I. W., and C. & G. S.
NEVADA	
Reno	University of Nevada.
NEW YORK	
Albany	University of State of New York.
*Buffalo	Canisius College (Jesuit).
*Ithaca	Cornell University.
*New York	Fordham University (Jesuit).
New York	American Museum of Natural History.
OHIO	
*Cincinnati	St. Xavier College (Jesuit).
Cleveland	John Carroll University (Jesuit).
PENNSYLVANIA	
*Pittsburgh	University of Pittsburgh.
*Philadelphia	The Franklin Institute.
*State College	Pennsylvania State College.
Swarthmore	Swarthmore College (inactive).
PUERTO RICO	
San Juan	San Juan Magnetic Observatory, C. & G. S.
SOUTH CAROLINA	
Columbia	University of South Carolina, C. & G. S.
TEXAS	
Denton	John W. Crain (private station).
UTAH	
Salt Lake City	University of Utah.
VERMONT	
*Burlington	University of Vermont.
VIRGINIA	
*Charlottesville	University of Virginia.
WASHINGTON	
Seattle	University of Washington.
Spokane	Gonzaga University (Jesuit).
WISCONSIN	
Milwaukee	Marquette University (Jesuit).
*Madison	University of Wisconsin.
NEBRASKA	
Lincoln	The Nebraska Wesleyan University (proposed).

In addition to the stations which are marked with an asterisk, the following stations have cooperated recently with the Coast and Geodetic Survey in furnishing immediate information for the preliminary determination of epicenters:

The Observatory	Apia, Samoa.
Royal Observatory	Hong Kong, China (via Manila).
Carnegie Institution of Washington, Huancayo Magnetic Observatory	Huancayo, Peru.
Manila Observatory	Manila, P. I.

The Dominion Observatory	Ottawa, Canada.
Observatory del Ebro (Through St. Louis University, St. Louis, Mo.)	Tortosa, Spain.
Dominion Meteorological Observatory	Victoria, British Columbia.
Royal Observatory de l'Observatoire de Zi-Ka-Wei	Zi-Ka-Wei, China (via Manila).

TABLE 2.—***Strong-motion seismograph stations of the U. S. Coast and Geodetic Survey***

(Corrected to June 1, 1936)

Station		Accelerograph		Weed strong-motion seismograph	Displacement meter
No.	Location	6-inch tape device	12-inch tape device		
1	Balboa, Canal Zone	A_6			
2	Berkeley, University of California	A_6			
3	Eureka, Calif	A_6			D
4	Ferndale, Calif	A_6			
5	Oakland, Calif., City Hall, basement	A_6			
6	Oakland, Calif., City Hall, sixteenth floor	A_6			
7	Oakland, Calif., Chabot Observatory			W	
8	Sacramento, Calif., Federal Building	A_6			
9	Salinas, Calif., County Courthouse	A_6			
10	San Francisco, Calif., Alexander Building, basement		A_{12}		
11	San Francisco, Calif., Alexander Building, eleventh floor		A_{12}		
12	San Francisco, Calif., Alexander Building, sixteenth floor		A_{12}		
13	San Francisco, Calif., 450 Sutter, basement			W	
14	San Francisco, Calif., 450 Sutter, twenty-eighth floor			W	
15	San Francisco, Calif., Shell Building, sub-basement			W	
16	San Francisco, Calif., Shell Building, twenty-third floor			W	
17	San Francisco, Calif., Shell Building, twenty-eighth floor			W	
18	San Francisco, Calif., Southern Pacific Building, basement		A_{12}		D
19	San Francisco, Calif., Southern Pacific Building, fourteenth floor		A_{12}		
20	San Francisco, Calif., State Building, basement, room 18	A_6			D
21	San Francisco, Calif., Golden Gate Park			W	
22	San Jose, Calif., Bank of America Building, basement	A_6			
23	San Jose, Calif., Bank of America Building, thirteenth floor	A_6			
24	Suisun Bay Bridge, California	A_6			
25	Chicago, Ill., Museum of Science and Industry. (For emergency field use)	A_6			
26	Bishop, Calif	A_6			
27	Colton, Calif	A_6			D
28	El Centro, Calif	A_6			
29	Hollywood, Calif., Hollywood Storage Co., basement		A_{12}		
30	Hollywood, Calif., Hollywood Storage Co., penthouse		A_{12}		
31	Hollywood, Calif., Hollywood Storage Co., adjoining Pacific Gas & Electric Co. lot		A_{12}		
32	Long Beach, Calif	A_6			
33	Los Angeles, Calif., Chamber of Commerce, basement	A_6			
34	Los Angeles, Calif., Chamber of Commerce, twelfth floor	A_6			
35	Los Angeles, Calif., Edison Building, basement	A_6			
36	Los Angeles, Calif., Subway Terminal, sub-basement		A_{12}		D
37	Los Angeles, Calif., Subway Terminal, thirteenth floor		A_{12}		
38	Los Angeles, Calif., Vernon Central Manufacturing District	A_6			
39	Pasadena, Calif., California Institute of Technology	A_6		W	D
40	San Bernardino, Calif			W	
41	San Diego, Calif	A_6			
42	Santa Ana, Calif			W	
43	Santa Barbara, Calif	A_6			
44	Westwood, Calif., University of California at Los Angeles	A_6			
45	Missoula, Mont., University of Montana		A_{12}		
46	Bozeman, Mont., Montana State College		A_{12}		
47	Butte, Mont., Montana School of Mines		A_{12}		
48	Helena, Mont., University of Montana		A_{12}		

PRINCIPLE OF THE SEISMOGRAPH

3. In general a seismograph consists of a so-called steady mass which is suspended from a rigid support in such a manner as to form a vertical, inverted, or horizontal pendulum and so that, due

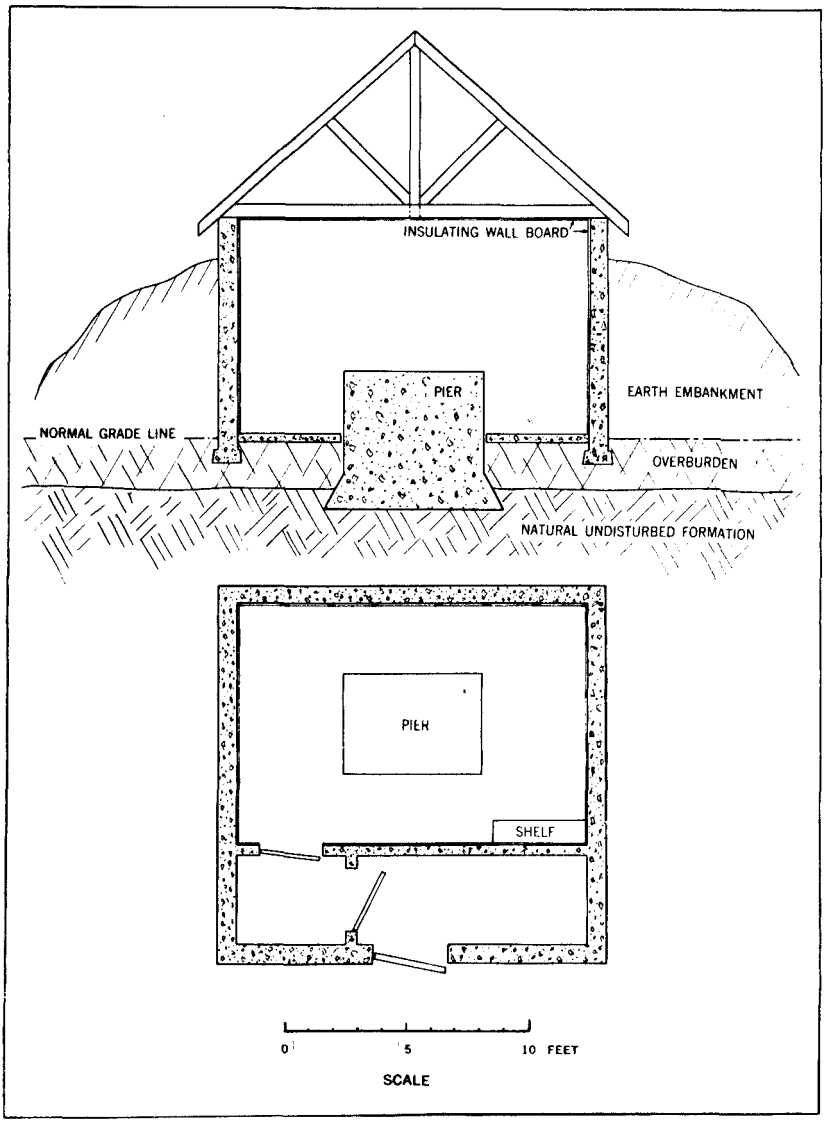

FIGURE 6.—Plan and sectional elevation of a seismograph building.

to its inertia, it will tend to remain at rest during a seismic disturbance and record, mechanically or photographically, the motion of the ground relative to the center of oscillation of the pendulum. Since the pendulum must be supported indirectly by the earth it will be set into vibration to a certain extent in its own natural period

by the earth vibrations and the resulting record will not be a true record of the ground displacement. If the period of the ground wave is about the same as that of the pendulum the amplitudes of the latter may become very large due to resonance. This resonance effect can be reduced to a great extent by damping of the pendulum by one of the methods described later.

The boom of the horizontal pendulum seismometer is pivoted or hinged to a rigid support in such a manner that it is free to oscillate in a horizontal plane about an axis which is approximately vertical and so that the center of gravity of the system is eccentric to the axis of rotation. If such a pendulum is set into vibration it will oscillate about its axis of rotation and finally come to rest with the center of gravity of the moving system in a vertical plane through the axis of rotation. The angle between the vertical and the axis of rotation is known as the forward tilt of the axis. As this angle of inclination is made smaller the period becomes longer until a position of instability is reached. Horizontal pendulum seismographs which are designed for registration of distant earthquakes are usually adjusted so that the natural periods will have values ranging from 6 to 15 seconds or more, depending upon the type of instrument and the character of the installation.

In the vertical component seismometer the boom and mass are balanced against a vertical spring so that the center of oscillation of the vertical pendulum thus formed is free to oscillate only in a vertical line and is sensitive only to the vertical component of the ground motion.

In order to provide a more complete picture of the ground movements during an earthquake it is good practice to provide three separate instruments for recording the ground vibrations in three directions at right angles to each other, that is, two horizontal pendulums and a vertical.

4. Magnification.—Ground motions resulting from distant earthquakes are usually so small as to be imperceptible. Therefore, a seismograph which is to be used for the registration of such quakes (teleseismic) should be so designed as to furnish a record of the ground motion, sufficiently magnified as to be useful in the identification of phases or for other studies. Magnification is usually secured by means of mechanical or optical levers, by electrodynamic methods (galvanometric registration) or by combinations of these methods.

In mechanical seismographs the **mechanical lever** may be simply the extension of the boom upon which the steady mass is mounted or it may be a light aluminum arm pivoted near one end in such a manner as to be free to oscillate in a horizontal plane with a minimum of friction. Its moment of inertia should be very small in comparison to that of the steady mass of the seismometer. The short arm is coupled directly to the steady mass or to an extension of the boom, while the longer arm terminates in a stylus which writes the record on smoked paper attached to a revolving drum. It is not practicable to use very high magnifications with mechanical recorders unless very heavy pendulum masses are used.

5. The optical lever as employed in photographic registration is used as follows: Light from a straight filament electric lamp or from

an illuminated slit, after collimation by a long focus lens is allowed to fall upon a mirror mounted on the boom near the axis of rotation of the seismometer pendulum or upon a mirror attached to a small multiplying lever coupled to the pendulum. After reflection from the mirror it is brought to a point focus on a sheet of photographic paper attached to a suitable recording drum. For all practical purposes the optical lever magnification is equal to twice the ratio of the distance from the collimating lens to the drum and the distance from the axis of rotation of the seismometer to the center of oscillation of the system. If, in addition, mechanical levers are used they must be taken into consideration in computing the total lever magnification.

The ratio of the amplitude on the seismogram to that of the corresponding earth wave at the station is the magnification of the

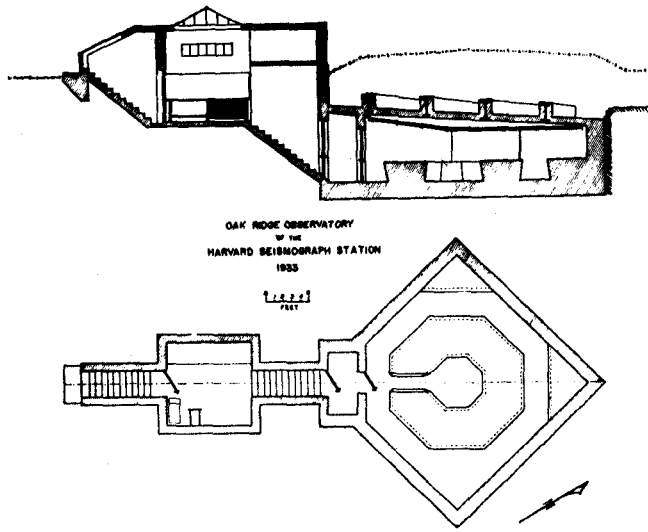

FIGURE 7.—Harvard University seismograph station, Harvard, Mass.

seismograph for simple harmonic motion. This is the product of the static and the harmonic magnification. The static magnification (for instruments not employing galvanometric registration) is simply the lever magnification (optical or mechanical or a combination of the two) and is equal to the limit which the harmonic magnification approaches for ground vibrations which are very rapid in comparison to the natural period of the pendulum. Harmonic magnification is a function of the ratio of the earth wave period to the period of the pendulum and of the character and magnitude of the damping. For zero damping this is infinite when the ratio of the above periods is unity.

5a. Electrodynamic magnification.[3]—In the case of galvanometric registration as used by Galitzin the maximum magnification

[3] Fürst B. Galitzin, Vorlesungen über Seismometrie (translation by O. Hecker, p. 300).

developed is equal approximately to the ratio of the electrodynamic constant of the seismometer to that of the galvanometer. In the system used by Wenner the above ratio should be multiplied by a factor equal to the ratio $S/(S+R)$, (fig. 17). The electrodynamic constant of a galvanometer or seismometer is the torque produced by unit current in the winding. (In the C. G. S. electromagnetic system the torque is expressed in dyne-centimeters and the unit of current is 10 amperes.)

DAMPING SYSTEMS

6. Air damping.—This type of damping is usually employed on the larger instruments of mechanical registration type. It consists essentially of a thin metal plate which is counterbalanced on pivots so that it swings freely in a metal housing or frame, with very little clearance. This mechanism is connected directly to the pendulum by means of a light but fairly rigid coupler.

7. Oil damping.—Just as in the case of air damping, this type of damping is employed on the more massive instruments. The damping vane, or vanes, are connected directly to the boom or steady mass and are partly or entirely immersed in oil of suitable viscosity. In some systems the vanes move through the oil in a direction at right angles to their broad surfaces, while in other systems the vanes move in a direction parallel to their broad surfaces, with or without fixed vanes closely adjacent to the moving vane. Oil dampers, while simple of construction and easy of operation, are not very satisfactory.

8. Electromagnetic damping.—When a conductor is moved across a magnetic field in such a way as to cut the lines of force of the field, an electromotive force is induced in the conductor. If the conductor forms part of a closed circuit, this electromotive force will cause a current to flow in the circuit, and the direction of the current is always such as to set up a magnetic field which opposes the motion of the conductor across the lines of force. The retarding force is proportional to the velocity of the conductor.

In certain types of seismometers employing electrodynamic magnification, the moving systems may be damped to any desired degree by shunting, with a suitable resistance, the coils of the seismometer and galvanometer and the retarding force (electromagnetic damping) may be controlled directly by varying the resistance of the shunt, as this controls to a large extent the current which flows in both seismometer and galvanometer.

9. Magnetic damping.—In addition to the damping due to the counter electromotive force induced in the coils, there is a certain amount of magnetic damping which is due to Foucault currents (eddy currents) induced in the metallic parts (other than the coils) of the moving systems when these parts move in the magnetic field. The retarding action resulting from these eddy currents is of the same nature as that described above and is known as magnetic damping.

Instruments employing magnetic damping are so constructed that all or part of the boom of the seismometer consists of a pure copper vane which moves in a permanent magnetic field. The degree of damping is controlled in each case by altering the position of the magnet relative to the copper vane.

SEISMOGRAPH ROOM OR BUILDING

10. As teleseismic instruments are usually operated at relatively high magnifications, it is absolutely necessary that such instruments be installed on stable masonry piers, which rest on natural, undisturbed clay, gravel, or rock, and in general these piers should be independent of the floors and walls of the building in which they are located. The seismograph room should be dry, well insulated against temperature changes, and should be protected against wind effects if possible. A general plan and sectional elevation of a seismograph room and instrument piers is shown in figure 6. The seimograph room may be located in the basement of a building, provided the necessary precautions are taken to guard against artificial disturbances resulting from machinery, such as elevators, machine-shop equipment, etc. It is not essential that the recorders be mounted on masonry piers, but the supporting tables should be of heavy construction and should be attached securely to the floor. If the instruments employ direct photographic registration, it is necessary that the seismograph room be equipped with suitable light traps for entrance and exit while the recorders are in actual operation. It is important that ample working space on all sides of the instruments be provided.

In more elaborate installations, such as the Oak Ridge Seismograph Observatory of Havard University, near Harvard, Mass. (fig. 7), the seismograph vault is entirely underground. At this station the piers, floor, and walls of the room rest upon solid rock and it was found unnecessary to separate the piers from the floor.[4]

STATION REQUIREMENTS

11. Teleseismic station.—The general requirements for a teleseismic station may be summarized as follows:

A. Seismometers, including galvanometers, if electromagnetic systems are to be used. There should be one to three components of medium to high magnification, depending upon local conditions, microseisms, and type of instrument.

B. Recorder, photographic or mechanical, depending upon type of registration.

C. Housing; that is, seismograph room or special building.

D. Piers of sufficient size and stability to support the instruments.

E. Time-marking clock (or chronometer) equipped with suitable electrical contacts for operation of time-marking equipment.

F. Time-marking relay with necessary devices for production of suitable minute and hour marks on the seismograms.

G. Time service, to consist of reliable astronomical observations at the station or radio or other equipment for reception of United States Naval Observatory time signals.

H. Supplies for routine operation, such as photo paper, chemicals, dark-room equipment, and ruby lamps.

I. Services of assistant who is qualified to carry on all routine work, such as changing records, comparing and rating of clocks, making minor instrumental adjustments, and preparing the seismograms for interpretation.

J. Interpretation of records. The amount of time to be spent upon the study and interpretation of the finished seismograms will depend entirely upon local conditions and supporting institutions.

K. Cooperation with other agencies or associations. Stations which cooperate with other agencies or associations by furnishing reliable information on all

[4] L. Don Leet, Bul. Seis. Soc. Am. vol. 24, no. 1, January 1934.

important earthquakes registered at the station or those which exchange information for special studies are of the most value in advancing the science and in increasing our knowledge of earthquakes.

12. Strong-motion station.—The general requirements for a strong-motion station are fewer in number, and the cost of operation should be much less, but the inspector or operator must be prepared and qualified to assume the responsibility of keeping the instruments in excellent condition at all times so that they will operate automatically and with precision at the time of severe earthquakes in the immediate vicinity of the station. The equipment will depend to some extent upon the type of instrument to be used, but for the most common of the strong-motion instruments, the accelerograph, the requirements are as follows:

A. Accelerograph, complete with a three-component accelerometer and automatic recorder.

B. Housing—that is, a seismograph room or small special building so constructed that it may be darkened for photographic work, but need not be equipped with light trap.

C. Pier, of sufficient size and stability to support the accelerograph. May rest directly upon a concrete or stone floor and need not be separated from walls.

D. Supplies (photographic paper) for routine, stand-by operation.

E. Services of a skilled observer who is capable of making fine instrumental adjustments, who understands thoroughly the technique of photographic recording and who is able and willing to carry out detailed technical directions for special or routine operation of the station.

COST OF ESTABLISHING A SEISMOGRAPH STATION

13. Teleseismic station.—The cost of establishing and operating a seismograph station for registration of distant earthquakes depends to a large extent upon the type and number of instruments to be constructed or purchased, the nature of the geological structure upon which the piers are to rest, and the kind of construction to be used in the seismograph building or room. Information on the cost of mechanical seismographs is not available, as instruments of this type are not constructed on a commercial basis in the United States. The cost of a single horizontal-component seismometer designed for photographic registration will vary from about $200 in the case of direct registration up to $1,000 for galvanometric instruments. These prices do not include recorders which may vary from $250 for a single component clock-driven or synchronous motor-driven drum up to $1,000 for a three-component recorder with open-time scale. Time-marking clocks with reliable circuit makers vary in price from $175 upward. The cost of a radio receiver will depend primarily upon the distance at which it is to be used from the sending station, but should not average more than $75. Single component, photographic recorders having a time scale of about 15 millimeters per minute can be operated for $35 to $50 per year (materials only).

13a. Strong-motion stations.—The cost of three component accelerographs varies from $1,000 to $1,200, depending upon the number of units purchased at one time. Installations are not expensive, however, as the piers may rest directly upon concrete floors, nor is the cost of operation high, as it is not continuous.

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14. Amateur stations.—It is possible to construct low magnification, inexpensive, mechanical seismographs which will respond to seismic waves resulting from the major earthquakes and which will furnish information of value to seismologists, provided the time as marked by the gram is accurate. Such instruments have been constructed and operated by Baldbridge [5], Seeburger [6], and others.

DESCRIPTIONS OF VARIOUS TELESEISMIC INSTRUMENTS

15. Bosch-Omori.—This instrument, figure 8, consists essentially of a heavy mass of 10 to 100 kilograms mounted on a boom and sus-

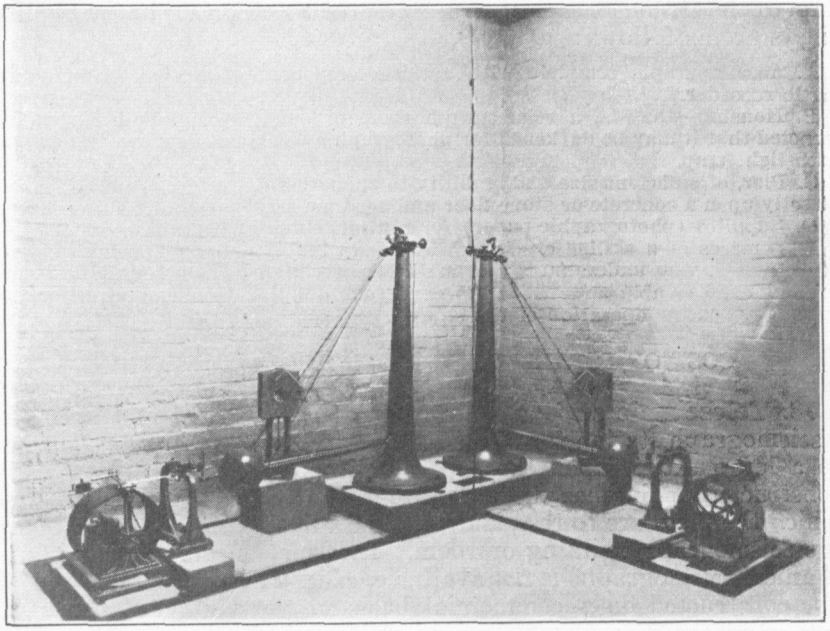

FIGURE 8.—Bosch-Omori horizontal component seismographs as formerly operated at Georgetown University, Washington, D. C. Now operated at Weston College, Weston, Mass.

pended as a horizontal pendulum from a massive column. The static magnification varies from 10 to 120, depending upon the value of the steady mass and the length of the multiplying levers. Registration is accomplished by means of a stylus which writes a record on smoked paper attached to a drum driven by clockwork. Oil or air damping is usually provided. The columns and recorders are bolted down to heavy masonry piers. Time marks are placed on the seismogram every minute by an electromagnetic device which lifts the stylus or moves it laterally a small amount.

16. Wiechert.[7]—The steady mass of this seismograph (fig. 9) is mounted near the top of a vertical column the lower end of which is

[5] R. H. Baldridge: Easily made seismograph, Popular Science Monthly, November 1935, p. 66.
[6] A. G. Ingalls: Amateur Seismology; Scientific American, April 1936, p. 194.
[7] H. F. Reid: On the Choice of a Seismograph; Bul. Seis. Soc., Am., vol. 2, no. 1, March 1912, p. 25.

supported by two pairs of flat springs under tension in such a manner as to permit freedom of motion of the steady mass in any horizontal direction. Light aluminum multiplying levers are connected to the steady mass and are so oriented and constructed as to permit of registration of two components of the motion at right angles to each other. Air dampers having a wide range af adjustment are also attached to the mechanical levers. Static magnification varies from 20 to 160 (and higher) depending on the size of the steady mass. The recorder is driven by a gravity clock whose rate is controlled by a revolving fan governor.

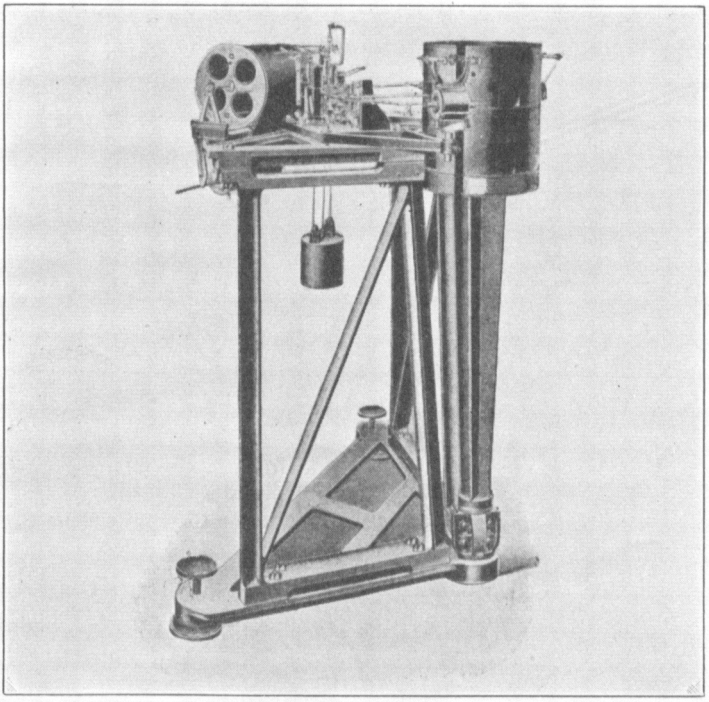

FIGURE 9.—Wiechert inverted, two-component, mechanical seismograph.

A vertical component Wiechert is shown in figure 10. The steady mass of 80 kilograms is mounted on a horizontal lever supported by a heavy helical spring. Air damping, similar to that of the horizontal component is used and registration is mechanical.

An inverted pendulum seismograph, somewhat similar to the Wiechert, but equipped with oil damping, is in operation at the University of Virginia. It was designed and constructed by the late A. J. Weed, and is shown in figure 11.

17. Wood-Anderson.[8]—In this instrument (fig. 12) the steady mass consists of a small copper cylinder or vane attached along one edge to a fine tungsten filament stretched taut. The filament is sus-

[8] J. A. Anderson and H. O. Wood: Description and Theory of the Torsion Seismometer; Bul. Seis. Soc. A., vol. 15, no. 1, March 1925, pp. 1–72.

pended from a rigid frame and its tension is fixed definitely by a small mass attached to its lower end. The filament acts as the axis of rotation of the system. The vane oscillates at right angles to the magnetic field of a permanent magnet attached to the frame, and magnetic damping of any desired degree may be obtained by ad-

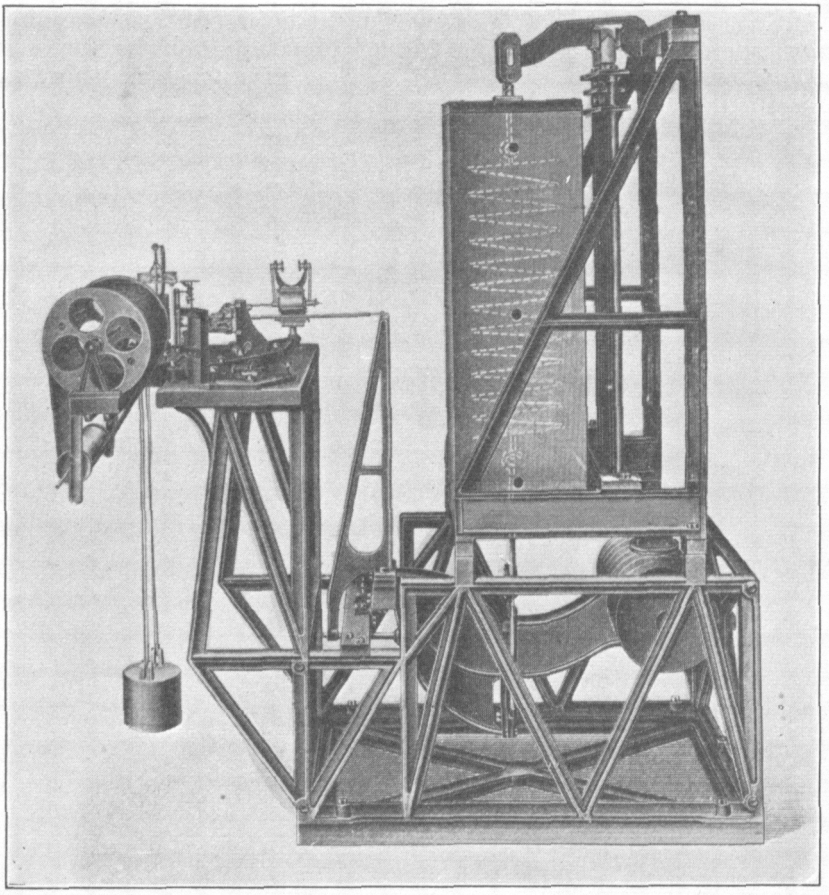

FIGURE 10.—Wiechert, vertical component, mechanical seismograph.

justment of the height of the magnet relative to the vane. A mirror is attached to the upper part of the vane for use in photographic registration. Static magnification varies from about 400 to 2,000, depending upon the type of steady mass and the length of the optical lever.

18. Milne Shaw.[9]—The Milne-Shaw seismograph (fig. 13) is a small horizontal pendulum having a steady mass of about 1 pound. It is designed for registration of distant earthquakes. A copper vane, attached to the boom in such a manner that it moves between the pole pieces of permanent magnets, provides magnetic damping. The damping is adjustable over a wide range by a simple adjustment of the air gap between the poles of the magnets. The static magnifi-

[9] Milne-Shaw handbook, J. J. Shaw, West Branch, England.

cation may be set at 150 or 250 and is accomplished by means of a system of mechanical and optical levers. Registration is photographic, the paper speed being 8 millimeters per minute on the recorders as furnished by Shaw.

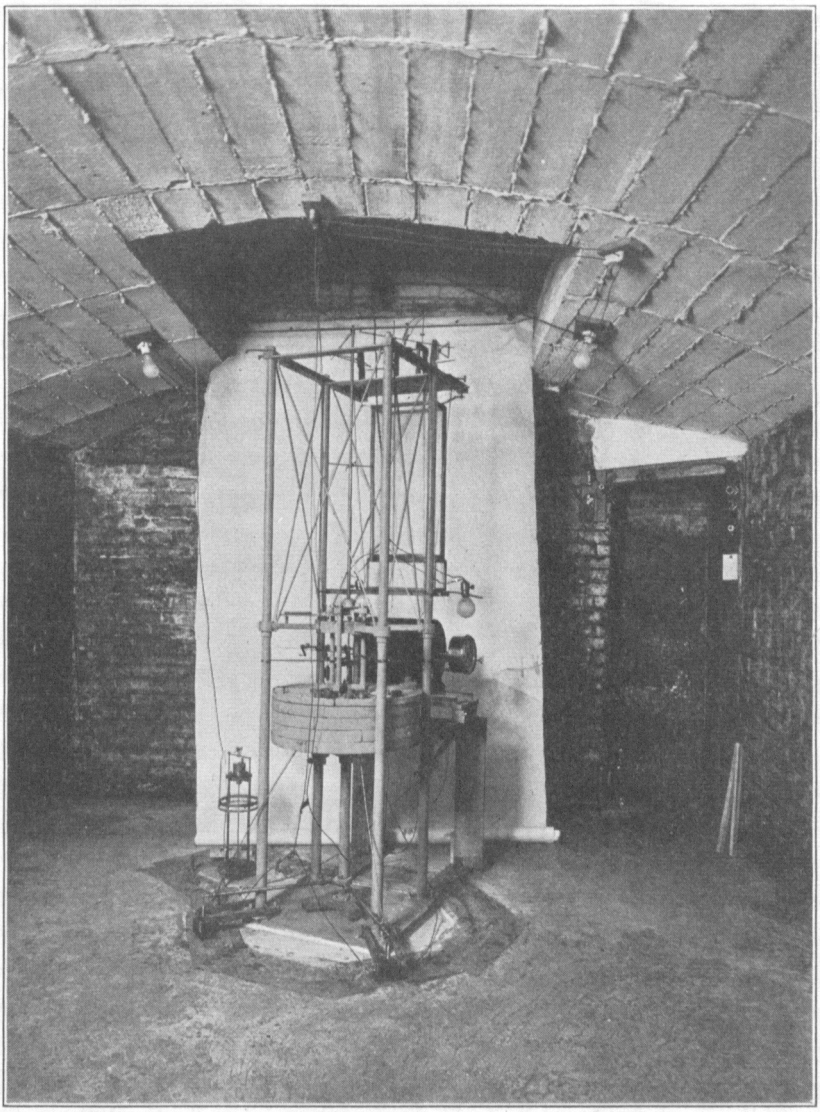

FIGURE 11.—Weed, two-component, mechanical seismograph as operated at the University of Virginia.

19. Galitzin (Wilip) horizontal component.[10]—The Galitzin system is designed for detection and registration of all important earthquakes. The steady mass is mounted upon a horizontal boom

[10] J. Wilip: On New Precision Seismographs; publication of the University of Tartu (Dorpat); 1926.

which is hinged to a rigid metal framework (fig. 14) by thin, flat steel springs under tension. The boom carries a series of copper coils which move at right angles to a strong magnetic field as the boom oscillates. These coils are connected in series with the coil of a high sensitivity galvanometer. As the coils move in the magnetic field of the permanent magnets a current of electricity is generated in

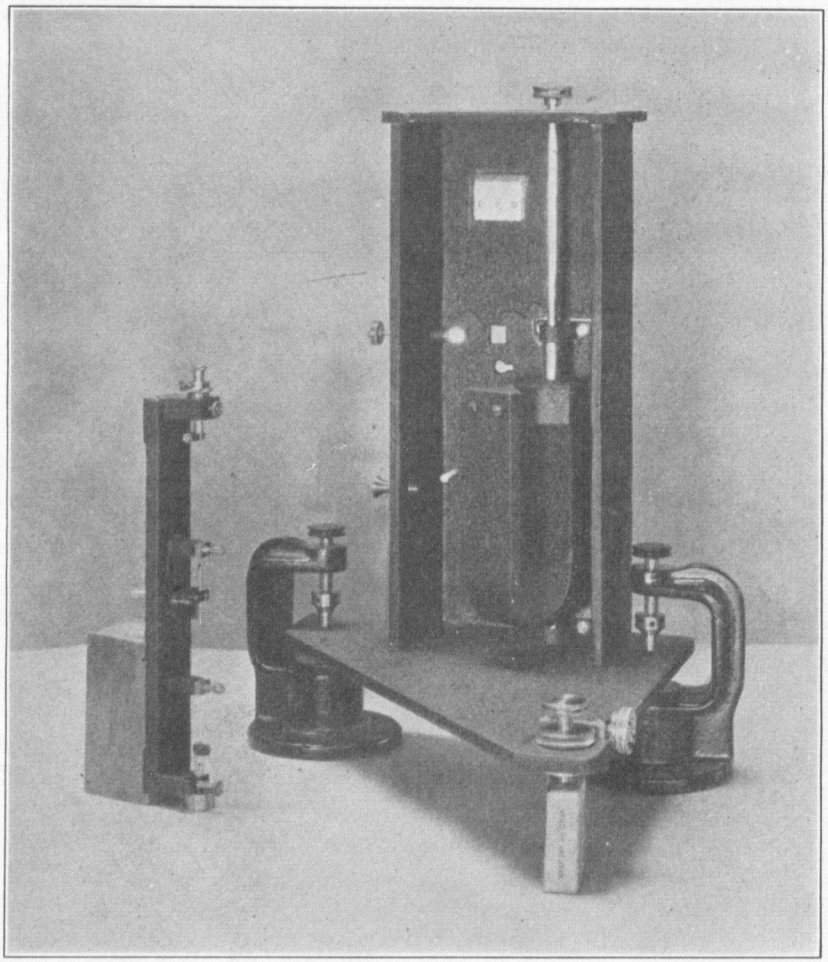

FIGURE 12.—Wood-Anderson torsion seismometer.

the circuit, which deflects the galvanometer by an amount depending upon the amplitude and period of the coils relative to the field. The amplitude of the angular motion of the galvanometer coil depends also upon the sensitivity of the galvanometer. The ground motions, highly magnified, are recorded photographically by reflection of a beam of light from the galvanometer mirror to a suitable recorder. Damping is magnetic and is accomplished by means of a copper vane attached to the end of the boom in such a manner that it passes freely

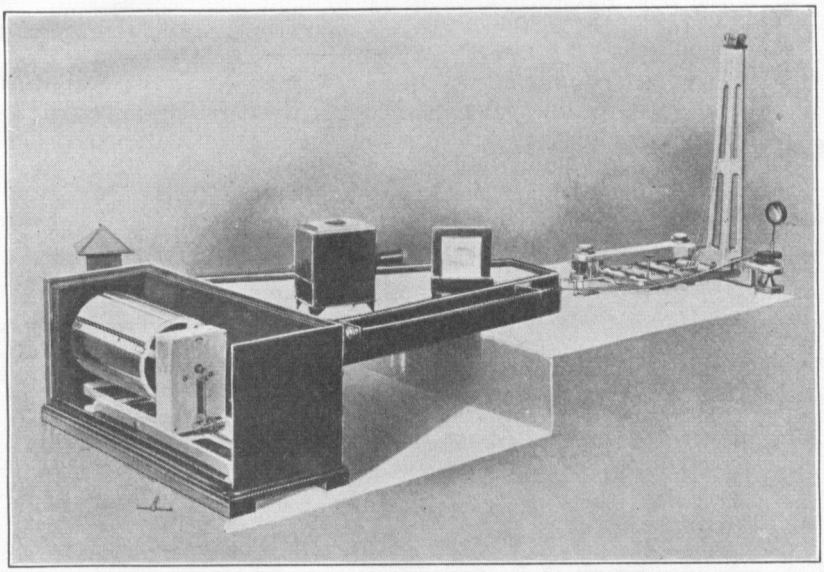

FIGURE 13.—Milne-Shaw horizontal component seismograph as operated at the cooperative station of the University of Chicago, U. S. Weather Bureau, and the United States Coast and Geodetic Survey.

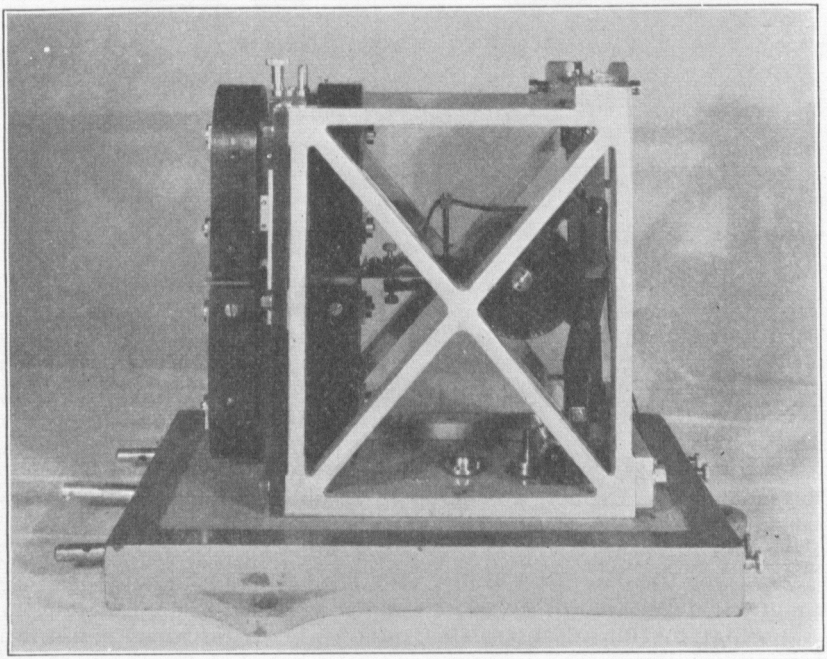

FIGURE 14.—Galitzin (Wilip) horizontal component seismometer, as operated at Fordham University, New York, N. Y.

between the pole pieces of a set of permanent magnets as the boom oscillates. In addition there is some electromagnetic damping in the circuit itself.

In the vertical component Galitzin (Cambridge), the boom and mass are balanced against a vertical spring in such a manner that the system is free to move only in a vertical plane and is sensitive only to the vertical component of the ground motion (fig. 15). Registration is galvanometric, as in the horizontal component.

20. Wenner.[11]—As in the Galitzin instrument, this seismometer, (fig. 16) is designed for galvanometric registration. The boom of the seismometer is hinged to a rigid column by very thin tempered

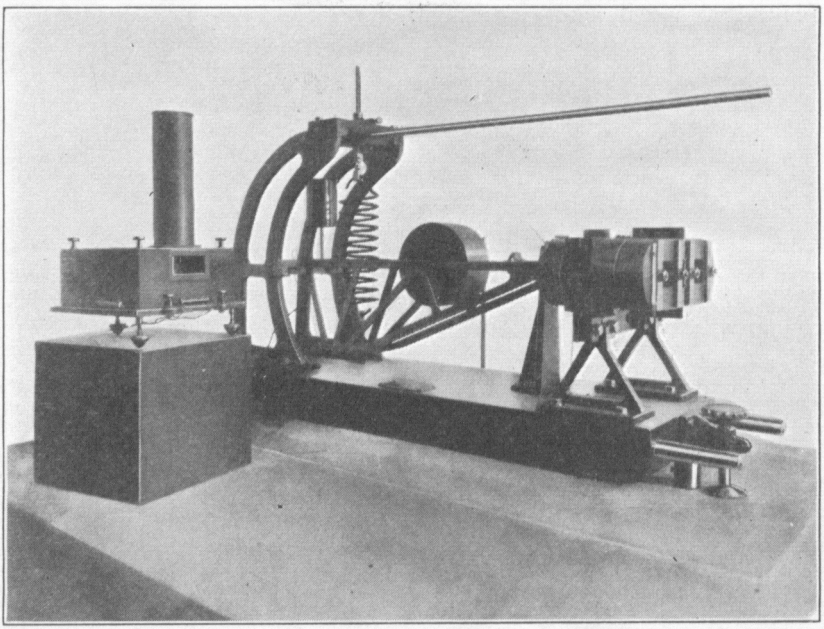

FIGURE 15.—Galitzin (Cambridge) vertical component seismometer and galvanometer as operated at Georgetown University, Washington, D. C.

brass hinges in such a manner that it is free to oscillate in a horizontal plane. The outer end of the boom carries a coil, the axis of which is concentric with cylindrical pole pieces fixed to permanent magnets attached to the base of the instrument. The coil is free to move in an air gap between the pole pieces, and the plane of the coil is parallel to the lines of force of a strong, permanent, radial magnetic field. The terminals of the coil are closed through a sensitive galvanometer with suitable shunt in parallel (fig. 17). If the seismometer coil moves in a direction at right angles to this magnetic field, a current is induced in the coil and the branch circuits, which in turn produces an angular deflection of the galvanometer which is much greater than the angular motion of the seismometer coil. Additional magnifica-

[11] Frank Wenner: A New Seismometer Equipped for Electromagnetic Damping and Electromagnetic and Optical Magnification; U. S. Bureau of Standards Journal of Research, vol. 2, May 1929, p. 963.

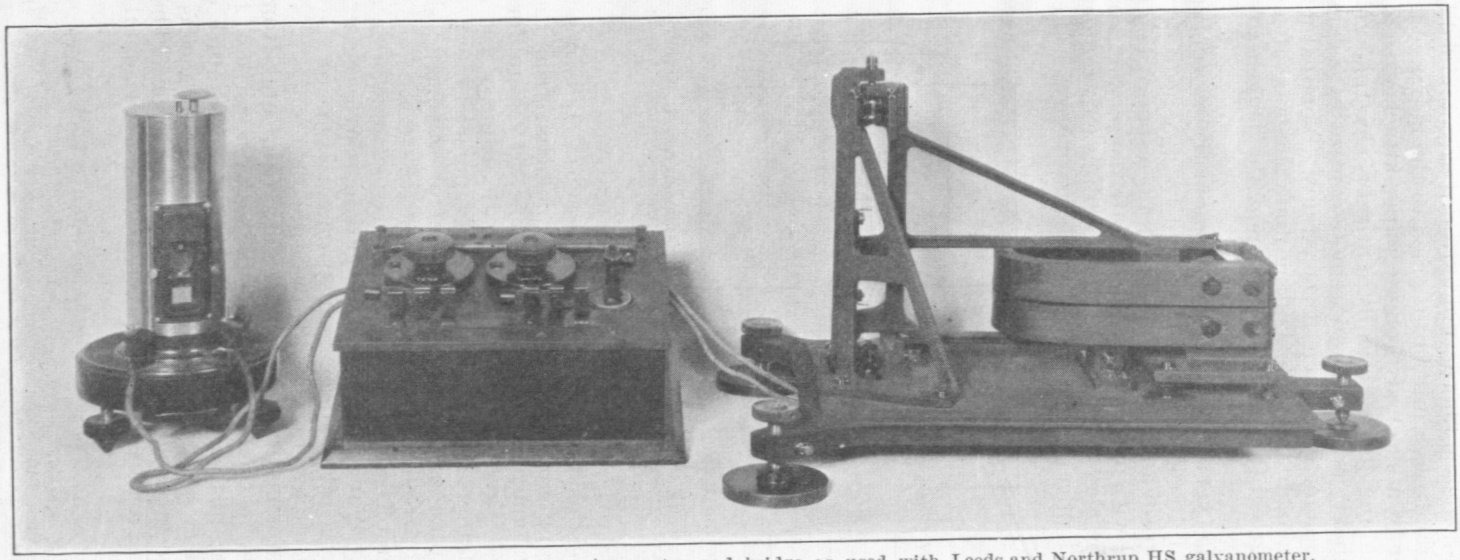

FIGURE 16.—Wenner horizontal component seismometer and bridge as used with Leeds and Northrup HS galvanometer.

tion and a continuous photographic record are obtained by reflecting a beam of light from a mirror attached to the moving element of the galvanometer to a sheet of bromide paper attached to a suitable recorder. Damping is practically entirely electromagnetic and is easily and quickly adjustable by remote control by means of a shunt across the seismometer branch of the circuit. Nominal magnification varies from 1,000 to 2,000, depending upon the type of galvanometer used, the degree of damping, and upon the length of the optical lever.

21. Benioff (vertical).[12]—This seismometer is equipped with a heavy mass of 100 kilograms suspended by a helical spring of such stiffness as to provide a period of about 1.0 second. The first models were provided with oil damping, but in later types damping is electromagnetic. The mass is coupled to a recording galvanometer through an electromechanical transducer of high sensitivity. The galvanom-

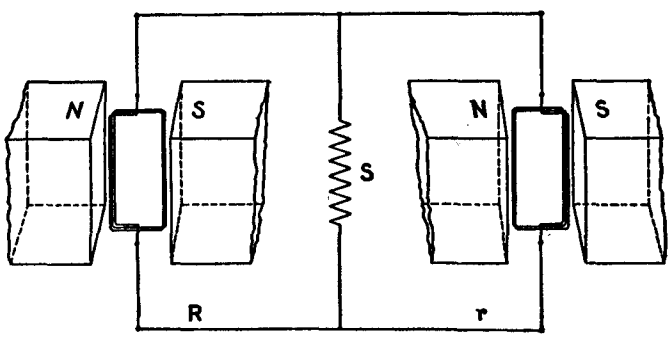

FIGURE 17.—Bridge circuit used with Wenner seismometer. (R is the resistance of the seismometer winding and leads connecting it to the recording station; r is the resistance of the galvanometer coil, suspensions and leads; S is the resistance of the bridge or shunt for adjustment of the damping of the system).

eter may be of the short- or long-period type. It is possible also to operate both long- and short-period galvanometers from the same seismometer simultaneously. Magnification is very high for the short-period ground waves, but drops off quite rapidly for the longer periods, depending upon the type of galvanometer used. A Benioff seismometer, photographic recorder, control panel, and short-period galvanometer, are shown in figure 18.

22. The Benioff horizontal component seismometer is also of the short-period type and is designed for galvanometric registration similarly to the vertical component instrument. One of the horizontal component seismometers is shown in figure 19.

23. Tilt-compensation seismometer (McComb-Romberg).[13]—The elimination of the troublesome effects of a slow tilt of the ground, the pier or the instrument columns, due to temperature changes or other causes, is accomplished in this instrument by means of viscous coupling between the boom and the multiplying lever. The multiplying lever carries a mirror and is pivoted about a horizontal axis. The

[12] Hugo Benioff: A New Vertical Seismograph; Bul. Seis. Soc. Am., vol. 22, no. 2, June 1932, p. 155.

[13] Arnold Romberg: Theory of a Nontilt Seismograph; Bul. Seis. Soc. Am., vol. 9, 1919, p. 135. H. E. McComb, Bul. Seis. Soc. Am., vol. 21, no. 1, March 1931. H. E. McComb, *Proc. Fifth Pac. Sci. Congress, Univ. of Toronto Press*, 1934 (A7–38).

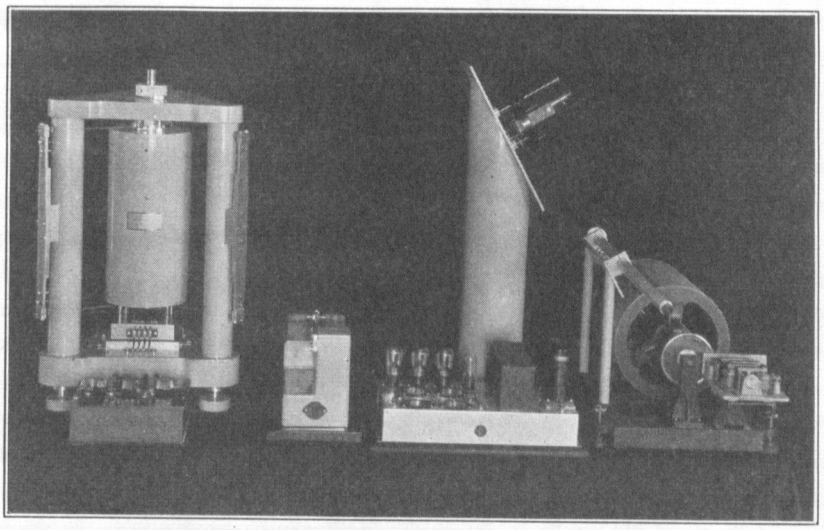

FIGURE 18.—Benioff vertical component seismometer, galvanometer, recorder and control units.

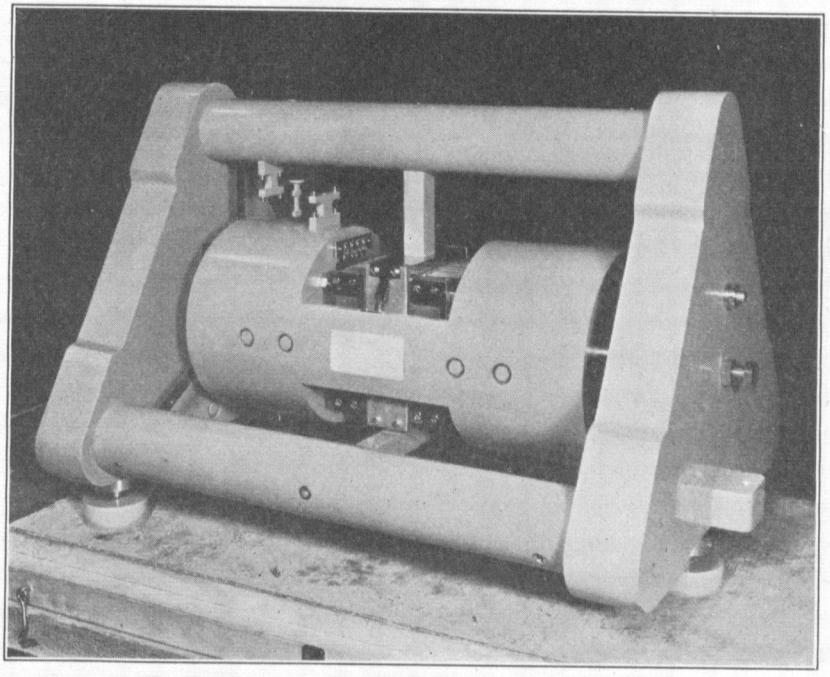

FIGURE 19.—Benioff horizontal component seismometer.

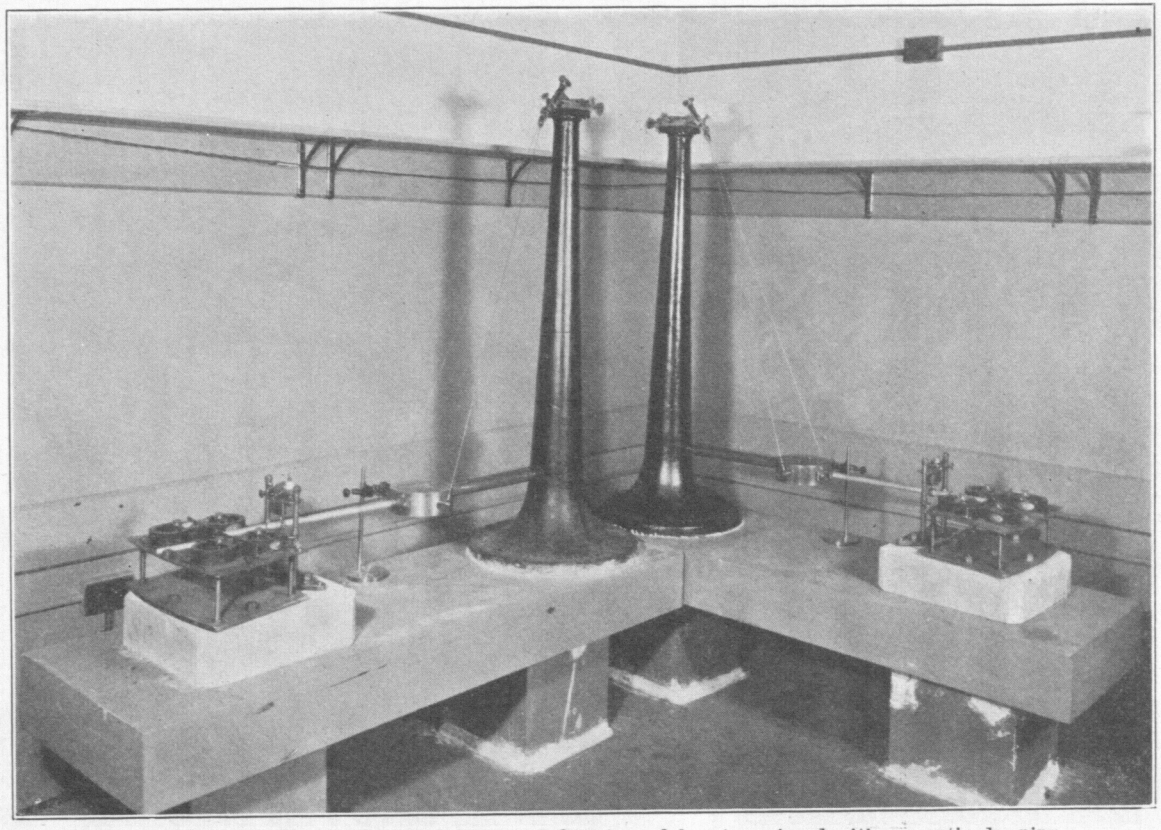

FIGURE 20.—Tilt-compensation (Modified Bosch-Omori pendulums) equipped with magnetic damping.

lower end of the lever terminates in a light, rigid vane submerged in oil. Normally this lever hangs vertically under the action of gravity and the mirror remains horizontal. For earth periods ranging from a small portion of a second up to 30 or 40 seconds, the vane follows the oil without appreciable loss of amplitude, but for very slow periods of several minutes or hours, the lever compensates continuously and the mirror remains horizontal.

Three sets of instruments of the Bosch-Omori type have been redesigned by the Coast and Geodetic Survey for tilt-compensation,

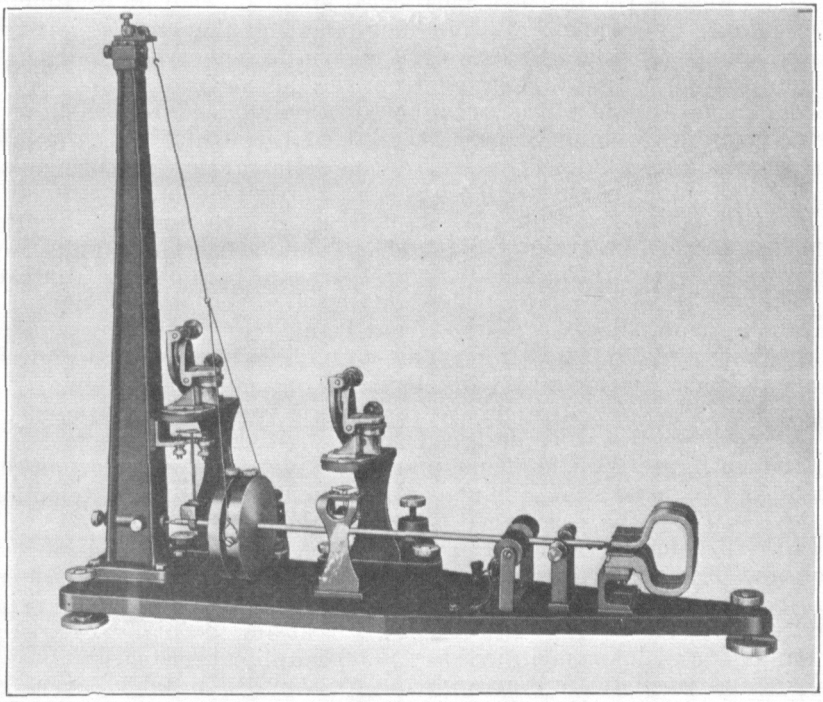

FIGURE 21.—Tilt-compensation seismometer (McComb-Romberg) with high and low magnification multiplying levers.

photographic registration, and oil damping. Two more of these instruments have been similarly redesigned, but equipped with magnetic damping, figure 20. A small model instrument, designed for high and low magnification and magnetic damping is shown in figure 21. Normal static magnification ranges from 6 to 330, depending upon local requirements.

24. Other seismographs.—There are many other types of teleseismic instruments, practically all of which are based upon the principle of the horizontal or vertical pendulums. Each has its field of usefulness, but in many cases the instruments are of special design to suit local conditions, only one instrument or component being in existence. In other cases the instruments are quite elaborate and require not only special buildings or vaults for their installation but special auxiliary equipment for their operation, as, for example,

the linear-strain seismometer as designed by Benioff [14] and operated successfully at the seismological laboratory in Pasadena.

SEISMOGRAPH RECORDERS

The apparatus for recording the motion of the seismometer pendulum is of equal importance to the seismometer itself. Without a continuous uniform record of the motion of the seismometer relative to the ground the latter is of little value.

25. A photographic recorder consists essentially of the cylindrical drum which is rotated at a peripheral speed of 8 to 60 millimeters per minute by a spring clock or motor, and at the same time translated along its axis at a rate of 3 to 5 millimeters per hour. The beam of light which is reflected from the mirror on the seismometer boom or galvanometer is brought to a point focus on a sheet of photographic bromide paper attached to the drum. The bromide paper after development is called the seismogram. Recorders are usually designed so they will furnish a record of 24 to 26 hours' duration without interruption. A simple clock-driven recorder is shown in figure 22. A straight filament galvanometer lamp and time-marking device are contained within the metal tube on the front of a light-tight recording box. The box contains the clock and the recording drum, the face of the drum being close to a long window just above the lamp housing. The cylindrical lens, which is adjustable in focus, is mounted directly in front of the window. This recorder is designed for use with a single component seismometer. A clock-driven recorder designed for use with two galvanometers is shown in figure 23. The time-marking device on this recorder consists of two glass flags mounted on the armatures of two telephone relays. When the relays are energized the flags displace the light beams by a small amount and produce time marks on the seismogram without loss of record. Another two component photographic recorder is shown in figure 24. This recorder was constructed originally at the Hawaiian Volcano Observatory for mechanical registration, but was later modified for photographic registration by the Coast and Geodetic Survey and equipped with a suitable cover. In this recorder two adjustable prisms are mounted on the armature of a relay for use in production of time marks. The performance of this recorder—that is, the uniformity of rate of rotation—has been very satisfactory, the paper speed being 30 millimeters per minute.

26. Synchronous electrical motors are, of course, more satisfactory than spring clocks for driving seismograph drums, since the motion is continuous and quite uniform. The motor-driven recorder, as supplied with the Wood-Anderson and Benioff seismometers, is shown in figure 25. This recorder is driven by a synchronous clock motor or by a special motor which is controlled by a vibrating reed. Another recorder, which is convenient for seismometers employing galvanometric registration, is shown in figure 26. In this instrument the separate drums are mounted on a common shaft with a motor and gear box at one end. This recorder is supplied with or without metal covers.

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[14] Hugo Benioff: A Linear Strain Seismograph; Bul. Seis. Soc. Am., vol. 25, no. 4, October 1935, p. 283.

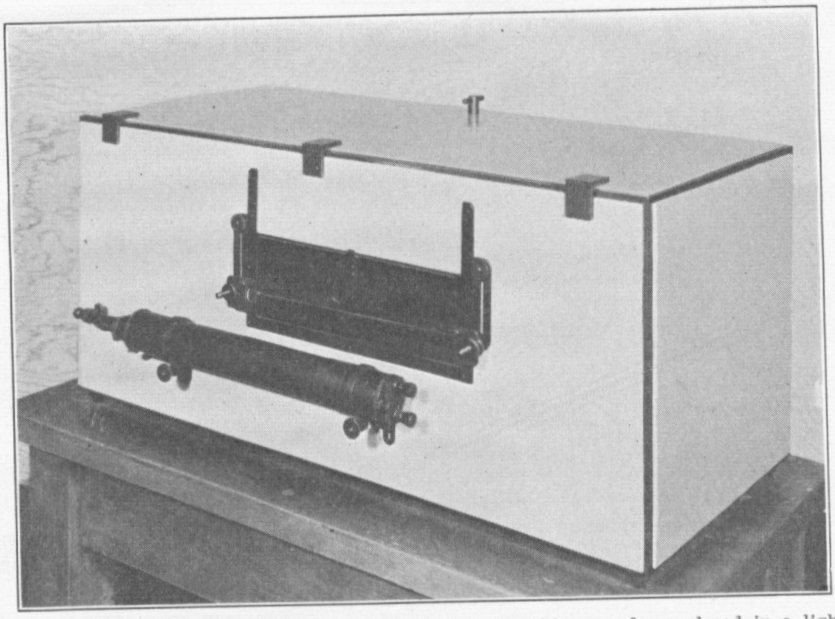

FIGURE 22.—A single component, clock-driven photographic recorder enclosed in a light-tight metal box.

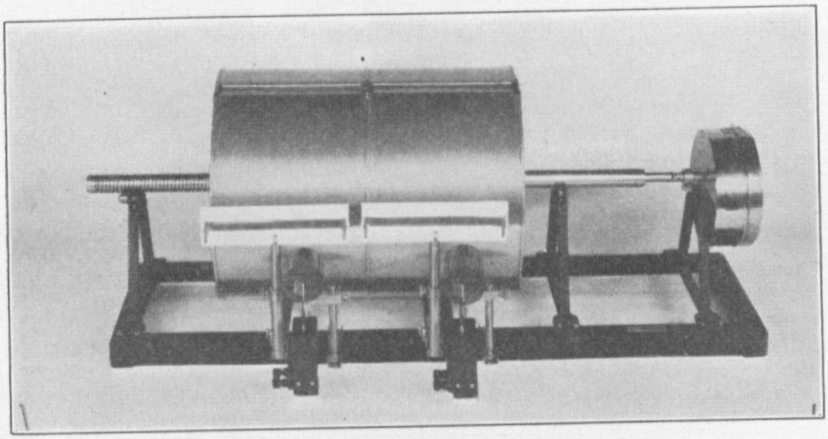

FIGURE 23.—A two-component, clock-driven, photographic recorder showing translation mechanism, and time-marking devices.

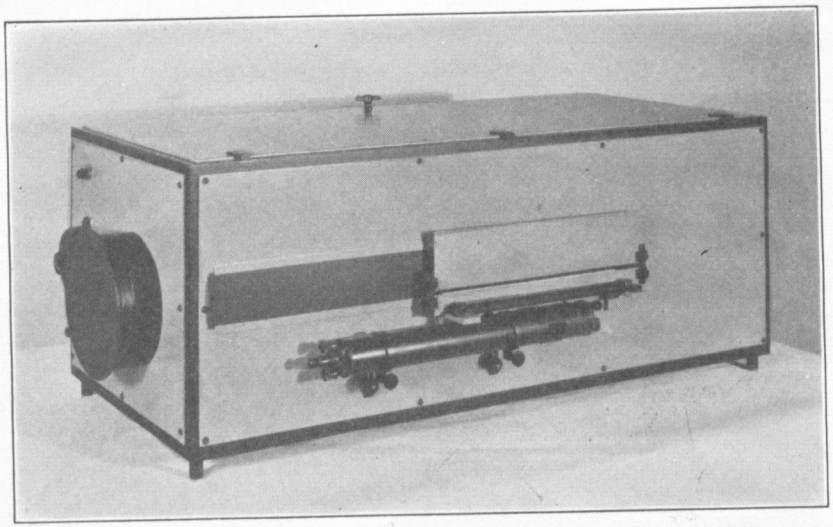

FIGURE 24.—A two-component photographic recorder equipped with a double prism time-marking element enclosed in the lamp housing.

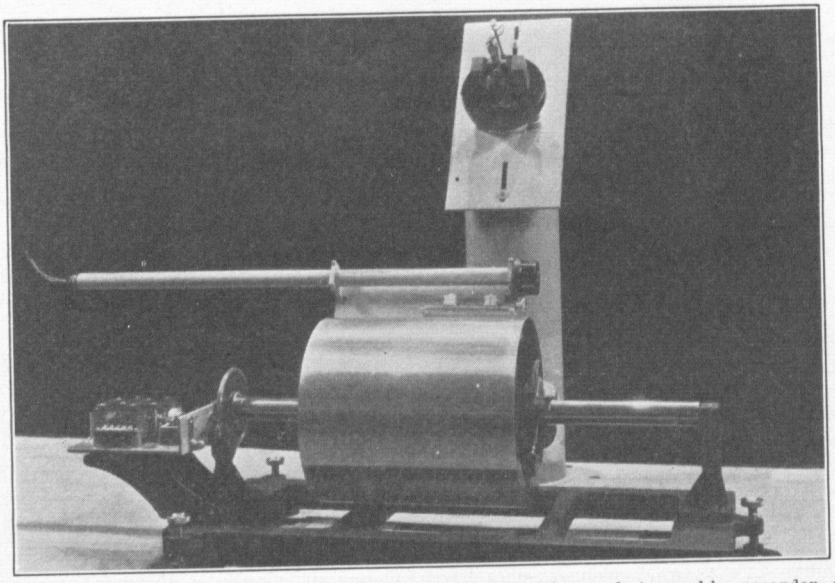

FIGURE 25.—A single component, synchronous motor-driven photographic recorder as supplied with Wood-Anderson and Benioff seismometers.

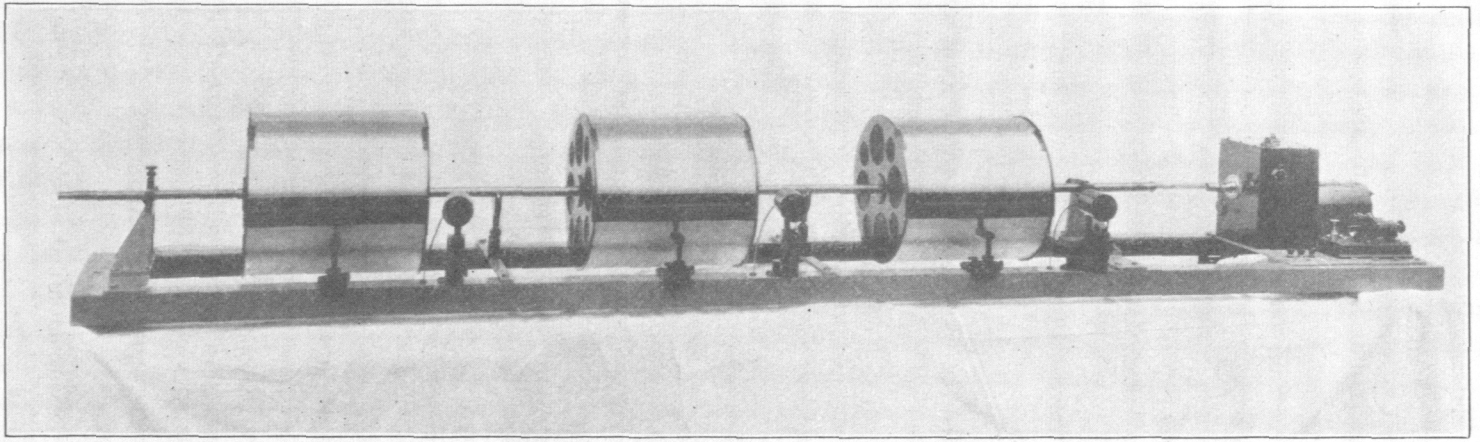

FIGURE 26.—A multiple drum photographic recorder, driven by a synchronous motor through a special gear box having a reduction of 57,000 to 1.

TIME MARKING EQUIPMENT

27. As it is necessary to know accurately the times of arrival of the different phases, it is essential that the standard time of the time marks on the seismograms be known to an accuracy of at least 1 second in teleseismic work and with much greater accuracy in studies of local quakes. It is essential also that the rate of rotation of the seismograph drum (paper speed) be uniform in order that the time marks be equally spaced. Pendulum clocks or chronometers with suitable circuit makers or circuit breakers are usually used for operation of time-marking equipment. A satisfactory form of circuit maker as used on pendulum clocks is shown in figure 27. The device for production of the hour marks consists of two levers which are held by a spring against a spiral cam, *A*. As the cam rotates with the minute-hand shaft the ends of the levers are pushed outward from the center of the cam. At one point on the periphery of the cam the spiral has an abrupt offset of about 3 millimeters. One of the levers is adjustable relative to the other in the direction of its long dimension. In practice the levers are so adjusted that the shorter lever drops from the offset of the cam making electrical contact with the other lever and a few seconds later the longer lever drops and breaks the circuit. The duration of the contact thus depends upon the positions of the ends of the levers relative to the offset. Similar levers are operated by a cam attached to the second hand at *S* and control the circuit which operates the mechanism for the production of the minute marks on the seismogram. These levers are usually adjusted so as to give a mark of 1 or 2 seconds' duration. In some cases the levers are equipped with an auxiliary device which omits the hour mark at noon and midnight but allows the minute mark to record, thus definitely identifying the hour marks.

28. In the case of mechanical recording on smoked paper the above circuits are closed through an electromagnet, the armature of which operates a mechanical marker or causes the writing stylus to be lifted or deflected laterally for an instant. The hour mark is either not used at all or the circuits are so arranged as to cause the sixtieth minute mark to be omitted each hour.

29. In photographic registration several methods are used for the production of time marks. The simplest method is to eclipse the light by an electromagnetic shutter, but this method results in some loss of record. The better method is to displace the incident light a small amount by means of a small piece of plane glass attached to the armature of the time-marking relay. This will result in a corresponding displacement of the light spot on the seismogram, so there will be no loss of record. A still better method is to pass the incident light through a 90° prism attached to the armature of the time-marking relay so that when the armature moves the incident ray is deflected through a very small angle, resulting in the desired displacement of the spot on the gram.

TIME COMPARISONS

30. The time-marking clock or chronometer should be compared daily with a reliable astronomical clock whose rate and corrections

are determined by astronomical observations or with United States Naval Observatory time signals, which are broadcast daily from

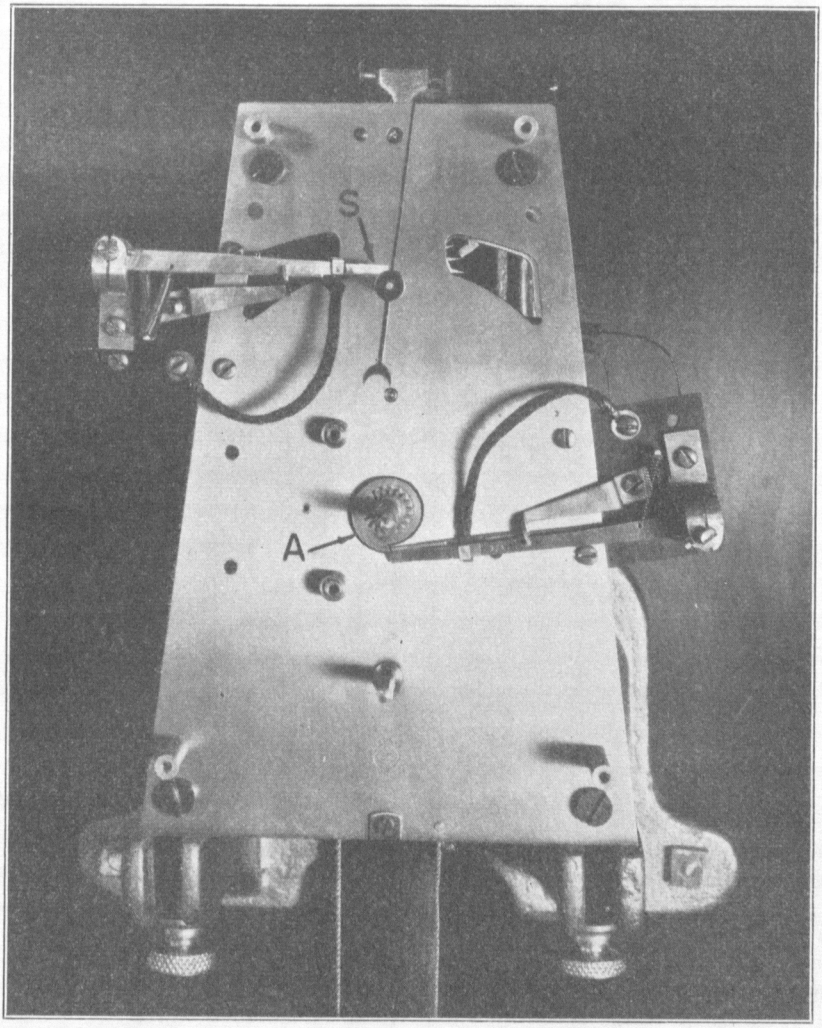

FIGURE 27.—Circuit makers as used on pendulum clocks for operation of time-marking equipment.

United States naval radio stations in accordance with the schedule given in table 3. Corrections and changes to this schedule are issued from time to time through the Hydrographic Bulletin, which is published by the Hydrographic Office of the United States Navy.

TABLE 3.—*United States Naval Observatory time signals*

[EFFECTIVE JUNE 15, 1936]

Tabular values are frequencies in kilocycles

Hour (Greenwich civil time)	Stations								
	NAA	NAA	NAA	NSS	NPG	NPG	NPG	NPM	NBA
0		113	9250		[1] 42.8				
1		113							
2									
3		113	9250	(2)	42.8	108	12885	16180	46
4									
5	[1] 64	113	4390						
6		113	9250						
7		113	9250						
8		113	9250	(2)	42.8	108	8590	8090	
9		113	9250						
10		113							
11		113							
12		113							
13		113	9250						
14									
15		113	[3] 9250						
16									
17	[1] 64	113	(4)	(2)	42.8	108	12885	8090	46
18		113							
19		113	9250						
20		113							
21		113	9250		[1] 42.8				
22		113							
23		113	9250						

[1] To be discontinued when 17.8 kc transmitter is put back into service.
[2] Only one of the following frequencies: 4015, 8030, 12045, or 16300 kc.
[3] Not transmitted on Sundays.
[4] All three of the following frequencies: 8150, 12225, and 16300 kc.

NAA = U. S. Naval Radio Station, Arlington, Va.
NSS = U. S. Naval Radio Station, Annapolis, Md.
NPG = U. S. Naval Radio Station, Mare Island, Calif.
NPM = U. S. Naval Radio Station, Pearl Harbor, Territory of Hawaii.
NBA = U. S. Naval Radio Station, Balboa, Canal Zone

TIME SIGNAL RECEIVERS

31. For the high-frequency signals, any high-grade short-wave receiver should be satisfactory. For the low-frequency signals it is necessary to provide special equipment. Schematic wiring diagrams of two simple and convenient low-frequency receivers are shown in figure 28 and the parts are listed in table 4. By use of special amplifiers and auxiliary equipment it is possible to record time signals on the seismograms automatically at distances quite remote from the transmitting station, but such equipment is quite complicated and somewhat expensive, and will not be described here.

TABLE 4.—*Radio receiver parts*

No.	Part	Circuit A	Circuit B
1	Double pole double throw switch		
2	Variable condenser, 0.001 mfd	43 plate	43 plate.
3	do	43 plate	43 plate.
4	Honeycomb coil (for 113 kc signal)	300 turns	None.
5	do	250 turns	250 turns.
6	do	200 turns	200 turns.
7	Grid condenser	0.00025 mfd	0.001 mfd.
8	Grid leak	4 megohm	4 megohm.
9	By-pass condenser	None	0.01 mfd.
10	Tube	201A	201A.
11	do	201A	201A.
12	do	201A	201A.

TABLE 4.—*Radio receiver parts*—Continued

No.	Part	Circuit A	Circuit B
13	Rheostat	30 ohm	30 ohm.
14	Ballast resistor		
15	do		
16	Amplifying transformer	Ratio 1:6	Ratio 1:6.
17	do	Ratio 1:6	Ratio 1:6.
18	Single pole single throw switch		
19	Single circuit jack		
20	do		
21	Two circuit panel jack		
	Coil mounting for honeycomb coils		
	"A" Power supply	6 volts d. c.	6 volts d. c.
	"B" Detector power supply	45 volts d. c.	45 volts d. c.
	"B" Amplifier power supply	135 volts d. c.	135 volts d. c.
	"C" Power supply	4½ volts d. c.	4½ volts d. c.

DESCRIPTION OF STRONG-MOTION INSTRUMENTS

32. Accelerograph.—This instrument (fig. 29) is used for recording photographically the horizontal and vertical motions of a building or of the ground in the vicinity of a moderate or destructive earthquake. It consists essentially of three accelerometers, a timing device, mechanisms for starting and stopping the apparatus automatically, and a photographic recorder, all of which remain inactive unless set into operation by the earthquake. The accelerometer is the element which is sensitive to ground motion. In reality it is a small seismometer having a natural period of one-tenth second. The moving element or vane is heavily damped by means of a cobalt-steel magnet. Light from a battery lamp is reflected from a mirror attached to the accelerometer vane and brought to focus on the photographic paper attached to the recorder. The three accelerometers are mounted with their axes at right angles to one another, the light from the three mirrors being brought to focus on the drum in the same horizontal line. It is thus possible to record three components of the motion simultaneously. The amplitude of the recorded motion is practically proportional to the ground acceleration for periods of the ground which are greater than about one-third second. Each accelerometer is equipped with a low-magnification attachment which furnishes an additional record of the earthquake at one-seventh the scale of the normal record. This insures obtaining readable records from both moderate and severe earthquakes. The automatic starting device consists of an oil-damped conical pendulum, which closes an electric contact if it moves in any horizontal direction by a small amount, thereby operating a relay which closes other circuits, the action of which starts the driving motor of the recorder, releases the brake on the time-marking clock, and turns on the battery lamp. After a short time the recorder and clock stop automatically and the light is extinguished unless the earthquake motion still persists. The recorder is designed for about 10 automatic operations before the paper is exhausted. Forty of these accelerographs, in addition to other types of strong-motion instruments, are now operated by the Survey in various seismic regions of the United States.

The results obtained with instruments of this type are being used in connection with the design of earthquake-resistant buildings and other structures.

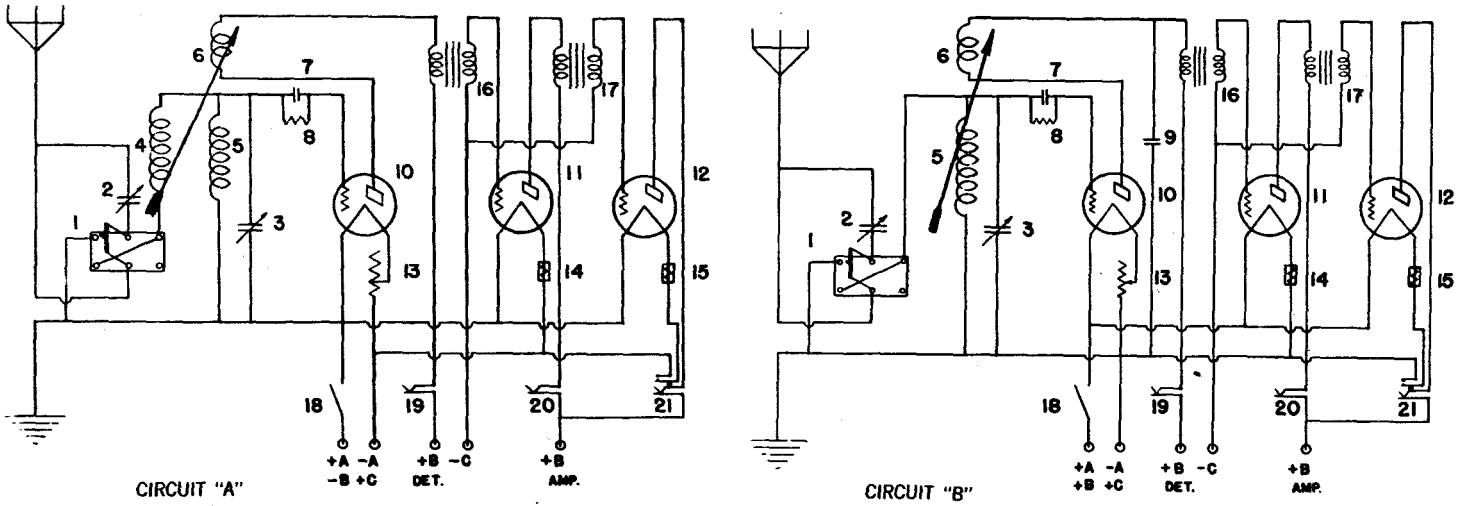

FIGURE 28.—Schematic wiring diagrams for low-frequency radio receivers for use in time-signal reception.

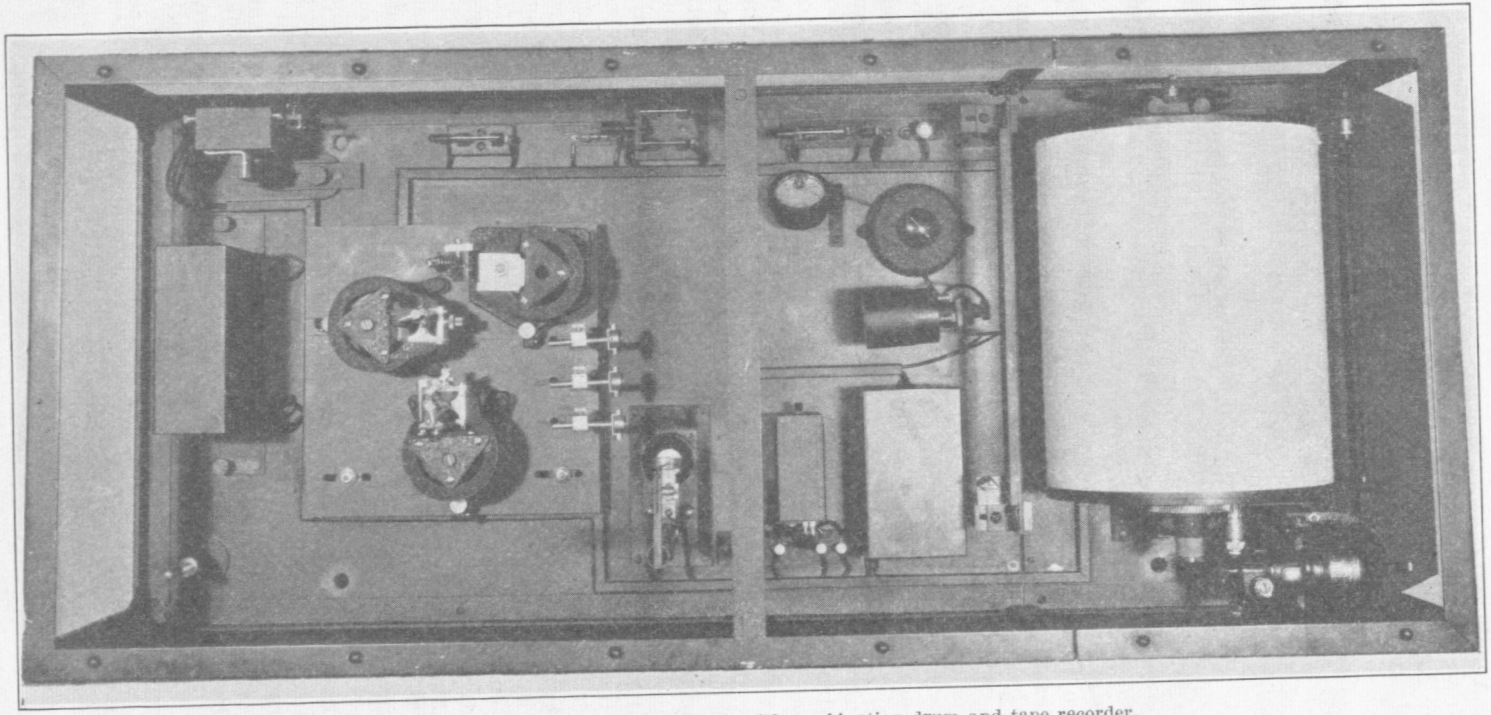

FIGURE 29.—Twelve-inch accelerograph with combination drum and tape recorder.

33. Accelerometers.—The accelerometers as used on the accelerograph were designed in their original form by Dr. Frank Wenner, of the National Bureau of Standards.[15] The instruments have been greatly modified since then by the Coast and Geodetic Survey. The instrument as used at present consists of a rectangular loop of copper pivoted eccentrically about one of its longer sides and coupled to a supporting frame by a helical spring so adjusted as to provide a natural period of 0.1 second to the system (fig. 30). The mirror which is used in photographic registration is a planoconvex lens silvered on the plane side and is attached to the vane. The side of the loop which is opposite the pivoted side is flattened into a vane and is free to oscillate in a narrow air gap between the pole pieces of a powerful cobalt-steel magnet, thus providing magnetic damping, which is adjustable over a wide range by a sliding shunt with indicator dial. An adjustable base line mirror is mounted on the suspension bracket at the same elevation as the vane mirror. A zero adjuster permits of easy and accurate adjustment of the light spot to any position on the face of the recorder. By a slight modification of the base the suspension system is mounted in such a manner as to serve as a vertical component. In practice three of these instruments are mounted close together on a common base and by suitable arrangement of prisms or stellite mirrors two of the accelerometers serve as horizontal components at right angles to each other and the third as a vertical component, all recording simultaneously on the same drum. A second mirror (facing upward on the horizontal component) is mounted on the axis of rotation of the vane and is directly below a reflecting prism attached to the bracket. The amplitude of the motion of the spot of light from the mirror is a function of the angle of inclination of the mirror to the axis of rotation. In practice the mirror is set at such an angle that the amplitude of motion of its spot will be about one-seventh that of the normal spot. By using such a device there is little chance of losing any record from the most severe earthquakes. This system, described by Schmidt [16] is shown schematically in figure 31.

34. Accelerometer (Neumann).—An instrument has been designed by Frank Neumann, of the Coast and Geodetic Survey, for use in the study of ground vibrations and vibrations in buildings and other structures. An experimental model is shown in figure 32. A steady mass of about 20 grams is mounted on the end of a flat spring of variable length for adjustment of the period. It is coupled to a mechanical multiplying lever carrying a mirror. The lever consists of a vertical spindle rolling upon flat, phosphor bronze ribbons in such a manner as to eliminate lost motion and at the same time operate at high static magnifications. Registration is photographic and damping is accomplished by means of oil between the lower surface of the steady mass and a flat piece of glass closely adjacent to it.

35. Displacement meter.—The displacement meters used by the Survey in the strong motion program are shown schematically in

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[15] Frank Wenner: Development of Seismological Instruments at the Bureau of Standards; Bul. Seis. Soc. Am., vol. 22, no. 1, March 1932, p. 60.

[16] A. Schmidt: Die Magnetischen Variationsinstrumente des Seddiner Observatoriums; Zeitschrift für Instrumentenkunde, May 1907, p. 137.

figure 33. Two horizontal oil-damped pendulums are mounted on a common base in such a manner that the booms are at right angles to each other. Registration is photographic and the records are made on two drums operated by a common motor. Static magnification

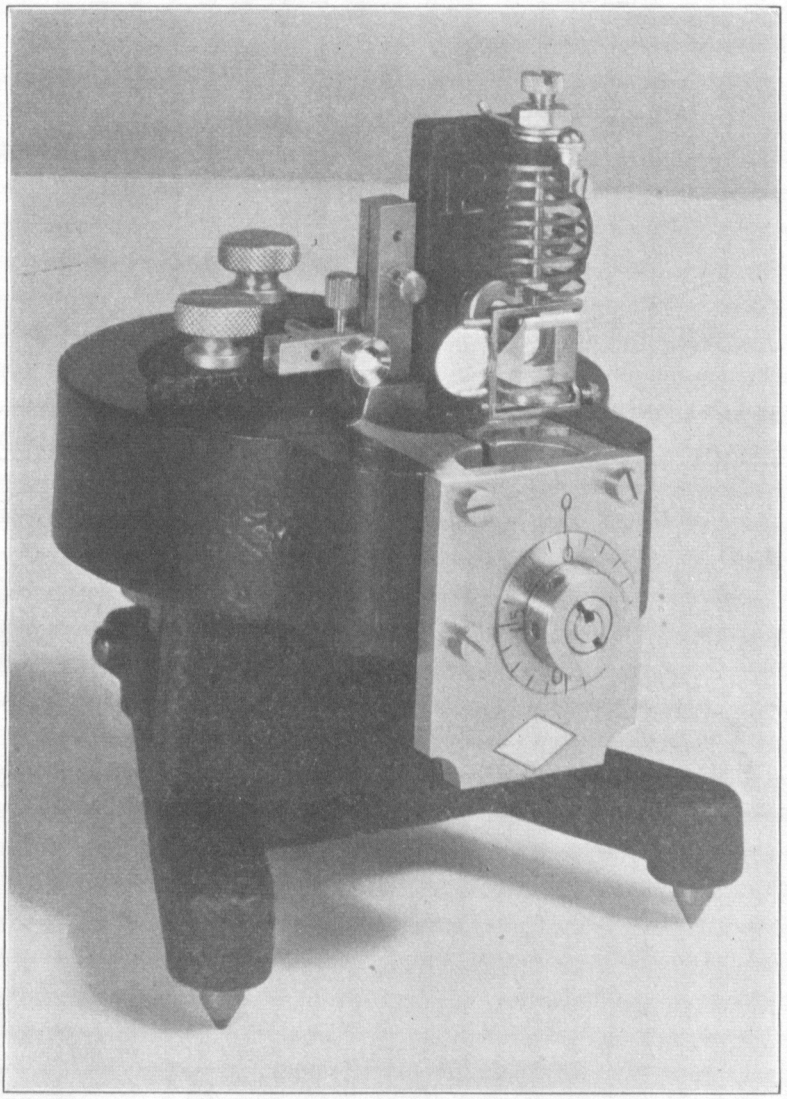

FIGURE 30.—Wenner accelerometer as modified by the United States Coast and Geodetic Survey.

is about 1.14. Time marks are placed on each drum automatically when the recorder is in actual operation. The starting mechanism is similar to that used on the accelerograph.

36. Weed, strong-motion seismograph.—This instrument, shown in figure 34, is designed for the registration of horizontal movements

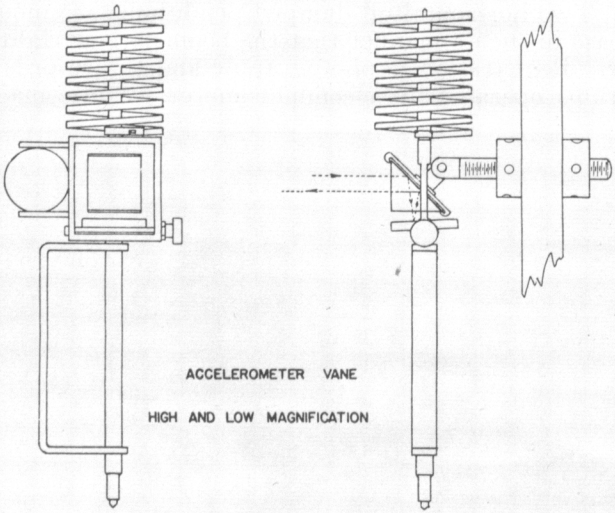

FIGURE 31.—Schematic diagrams of pivot and helical spring suspensions and low magnification device for accelerometers.

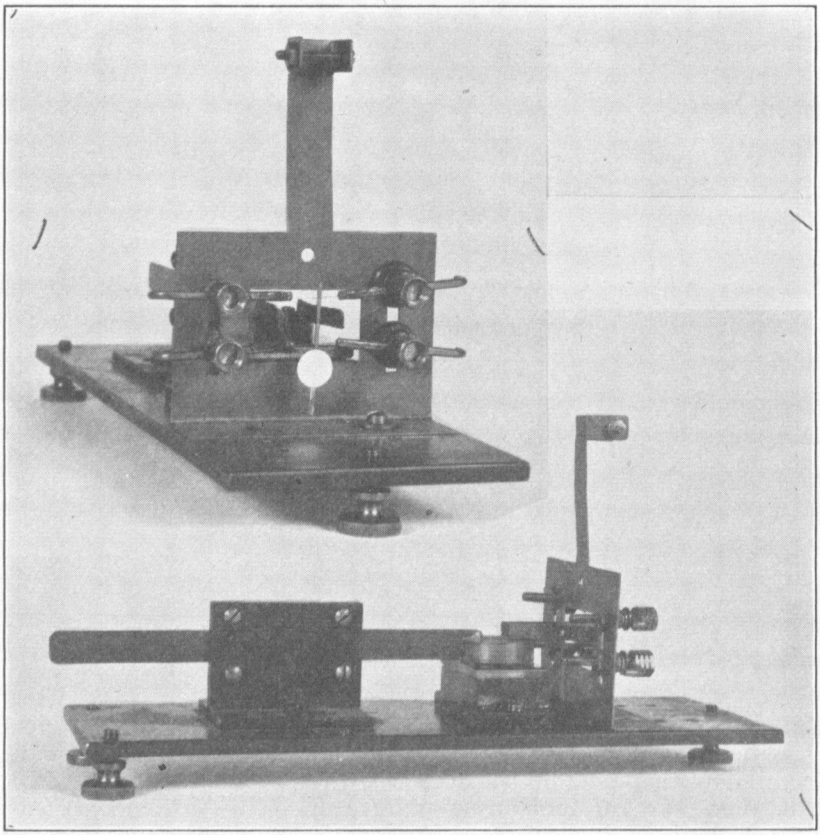

FIGURE 32.—Side and front view of experimental model of Neumann's accelerometer.

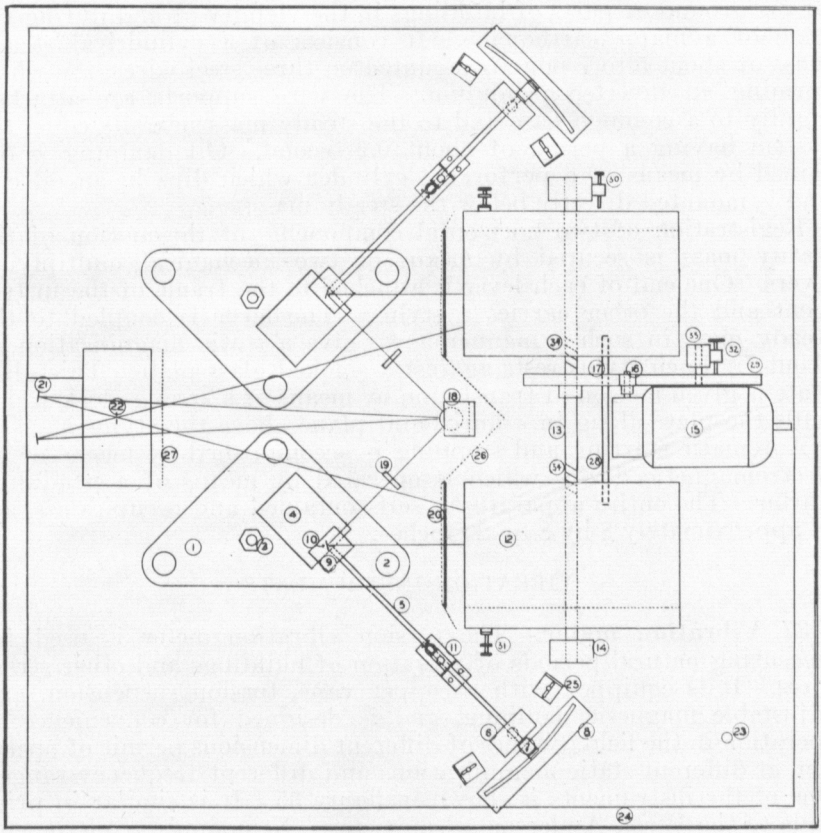

FIGURE 33.—Schematic diagram of two-component strong-motion displacement meter.

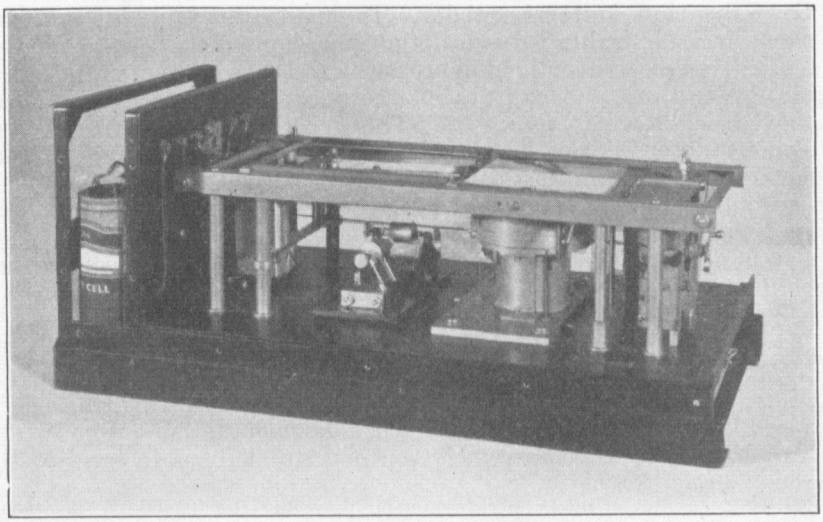

FIGURE 34.—Weed, strong-motion, two-component, mechanical seismograph.

of the ground or parts of buildings in the vicinity of and during the time of a major earthquake. It consists of a cylindrical steady mass of about 5 to 7 pounds mounted on three steel wires, the whole forming an inverted pendulum. The wire supports are attached rigidly to a common base and to the steady mass near its edge, the system having a period of about 0.2 second. Oil damping is obtained by means of a perforated cylinder which dips in an oil cup and is mounted directly below the steady mass.

Registration of two horizontal components of the motion of the steady mass is secured by means of two mechanical multiplying levers. One end of each lever is attached to the frame of the instrument and the other carries a stylus. The lever is coupled to the steady mass in such a manner as to give a static magnification of about 7. Each stylus rests against a smoked glass plate. This glass plate is given motion of translation by means of a spring clock which pulls the plate along in a horizontal plane above the styluses.

Automatic starting and stopping is accomplished by means of an electromagnetic device which is operated by means of a pendulum starter. The entire apparatus is self-contained and occupies a space of approximately 8 by 8 by 20 inches.

VIBRATION INSTRUMENTS

37. Vibration meter.—The torsion vibration meter is used for measuring natural periods of vibration of buildings and other structures. It is equipped with a copper vane, torsion suspension, and adjustable magnetic damping, and is designed for convenience of operation in the field. Vanes of different dimensions permit of operation at different static magnifications and different frequency ranges. One of the instruments is shown in figure 35. It is similar in principle to the Wood-Anderson seismometer. Neumann's accelerometer (see description, p. 36), also has been used in connection with the study of horizontal vibrations in structures and buildings.

38. Vibration meter recorder.—In making a study of building periods it is desirable to record the vibrations since resonance frequencies can be determined more accurately from the grams than from eye readings. A convenient photographic recorder, with cover removed, is shown in figure 36. This recorder is driven by a synchronous motor or by a 6-volt, direct-current motor having different gear ratios for obtaining different paper speeds. Convenient electrical outlets and switches make it possible to control from one station two or more of these recorders operating simultaneously on different floors of a building, time marks being simultaneous on all records.

TILT-METERS

39. The researches of Ishimoto [17] and others indicate that certain earthquakes have been preceded by a definite pattern of tilting of the ground. The Ishimoto tilt-meter is a horizontal pendulum which is so adjusted as to be extremely sensitive to changes in level of the

[17] M. Ishimoto; Bul. of the Eq. Res. Institute of Tokyo Imperial University, June 1930, p. 222.

foundation upon which it rests. The Merritt[18] tilt-meter, which is in use at three stations in California, operates on a different principle. In this instrument interference fringes between a plate of optical glass and the surface of a liquid are obtained. The glass plate is fixed to the foundation to be investigated and tilts with it,

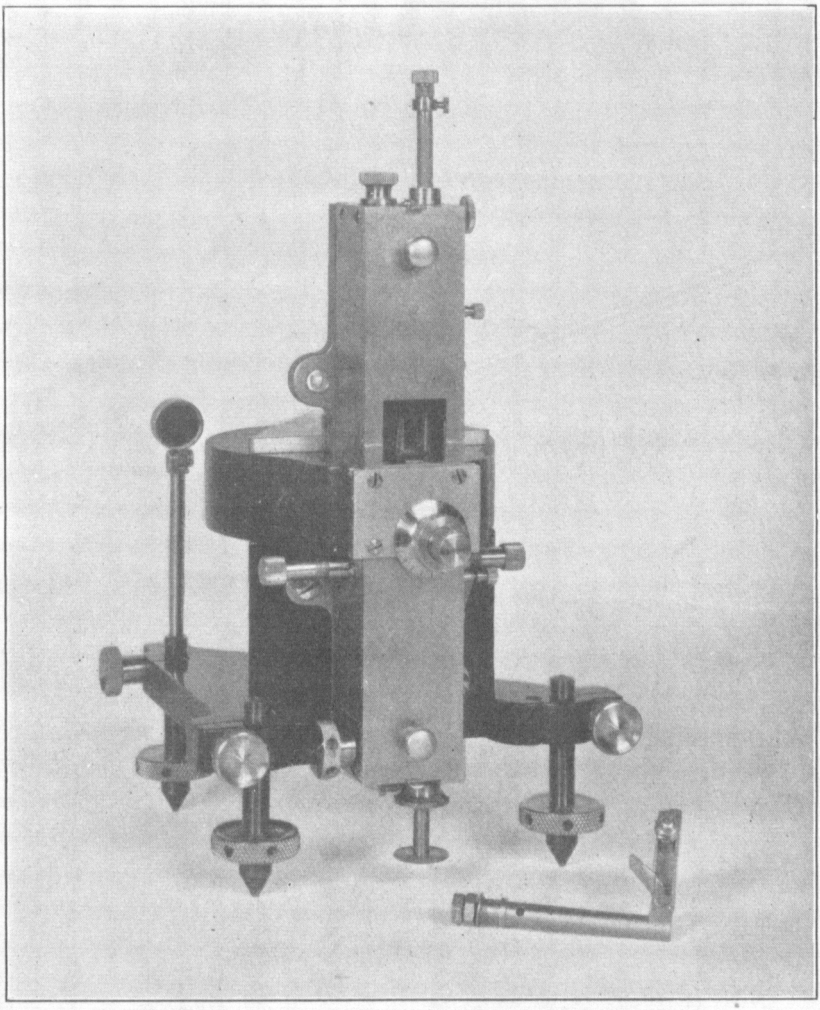

FIGURE 35.—Vibration meter, torsion type, for use in determining periods of buildings.

while the surface of the liquid remains horizontal. The change in the number of fringes crossing any reference line on the plate after a lapse of time is a measure of the tilt in the direction of the length of the line, hence readings taken on two lines at right angles provide measurements of both components of the tilt from one instrument.

[18] Geo. E. Merritt; National Research Council; Transactions of the American Geophysical Union, June 1932, p. 98.

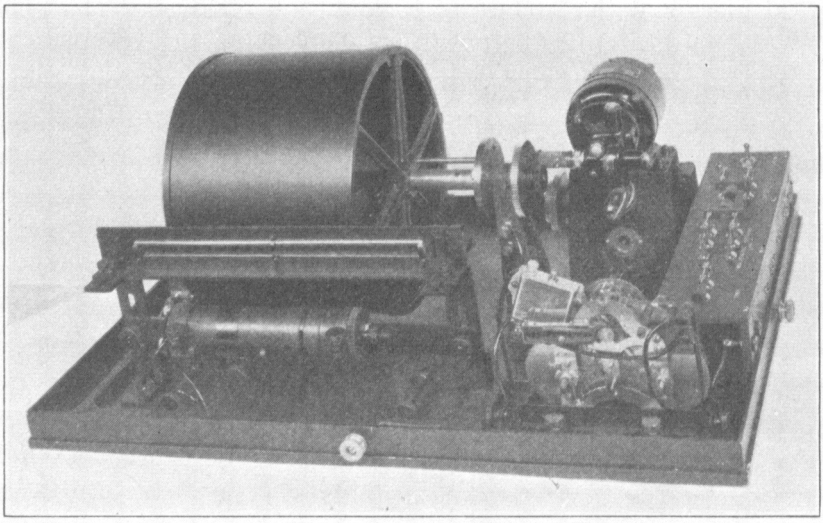

FIGURE 36.—Vibration meter recorder for use with vibration meters.

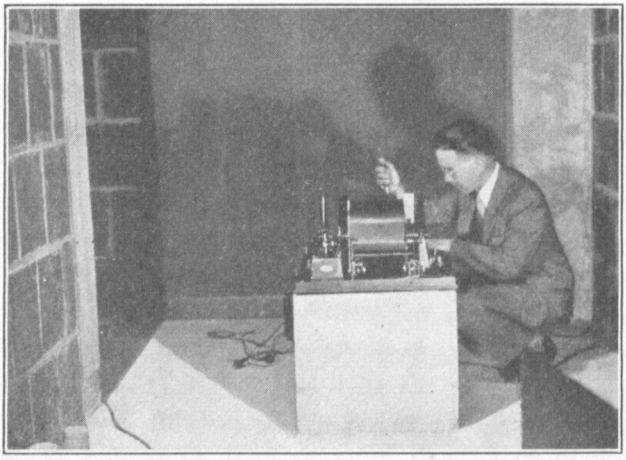

FIGURE 37.—Typical strong-motion seismograph station, showing a 6-inch accelerograph mounted on a concrete pier which rests directly on the floor of the building.

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