Seismological Instruments Developed at C. I. T.

By HUGO BENIOFF

INSTRUMENT development has been one of the principal activities of the Seismological Laboratory research program ever since it was started in 1921, under the direction of H. O. Wood, as a minor grant of the Carnegie Institution of Washington. The first instrument to be completed on this program was the torsion seismograph. It was invented by Dr. J. A. Anderson of the Mount Wilson Observatory staff and was developed jointly with H. O. Wood. Essentially, it is a horizontal pendulum in the form of a small mass eccentrically mounted on a taut wire suspension, as shown schematically in Fig. 1. Critical damping of the pendulum motion is provided by a permanent magnet. Horizontal vibration of the ground during the passage of an earthquake wave results in an angular vibration of the pendulum mass. This angular vibration is optically magnified and photographically recorded by means of the mirror attached to the pendulum and the recording drum assembly, as shown in the figure.

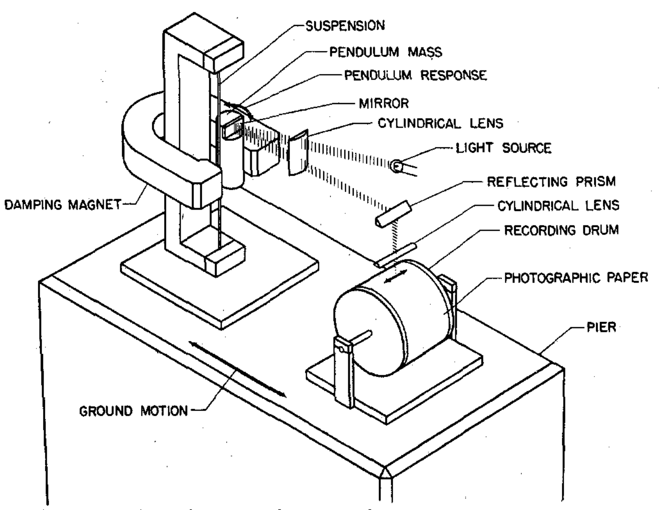

Fig. 1 Wood-Anderson seismograph.

For recording rapid earth movements such as those produced by nearby earthquakes, the pendulum mass is in the form of a small cylinder 2 mm in diameter and 25 mm long. The free period of the pendulum rotating about its suspension is 0.8 sec. With this instrument the magnification, defined as the ratio of light spot displacement to ground displacement, has a maximum value of 2800. For recording the slower wave-movements which are generally produced by distant earthquakes, the pendulum mass is built in the form of a rectangular plate with dimensions approximately 25x8x1 mm. This pendulum has a free period of 6 sec and a maximum magnification of 800. Each station of the California Institute network has two short-period torsion seismographs for recording respectively the north-south and east-west components of the earth movement. In addition, the main station at the Seismological Laboratory has two of the long-period instruments.

Another torsion seismograph in use at the Seismological Laboratory was designed by the late Dr. Sinclair Smith of the Mount Wilson Observatory staff for the purpose of recording strong earthquake movements. The maximum magnification of this device is 4. Instead of one pendulum mass this seismograph has two masses of unequal weight mounted at the ends of a horizontal bar, supported by a torsion suspension through its center.

For many problems the maximum obtainable magnification of the torsion seismograph is too low. Moreover, it was not possible to build a satisfactory torsion instrument for recording the vertical or up-and-down component of the ground motion.

To meet these difficulties a series of instruments was designed in which the pendulum movement generates electric power by means of a variable reluctance transducer. A galvanometer, actuated by this power, records the earth movements. The variable reluctance transducer is in effect an embodiment of the telephone receiver principle. Movement of the seismometer pendulum varies the lengths of a group of four magnetic air-gaps in such a way that two increase in length while the other two decrease in length. The resulting change in magnetic flux through the associated armatures produces an electric potential in the coils surrounding the armatures. The magnetic flux is supplied by a permanent magnet. In order to provide a large electrical output without recourse to amplifiers, the pendulum mass is made rather large, 100 kg (220 lbs). In the vertical component instrument (Fig. 2) the restoring-force is supplied by the supporting spring which is attached at the bottom of the hole in the cyl-

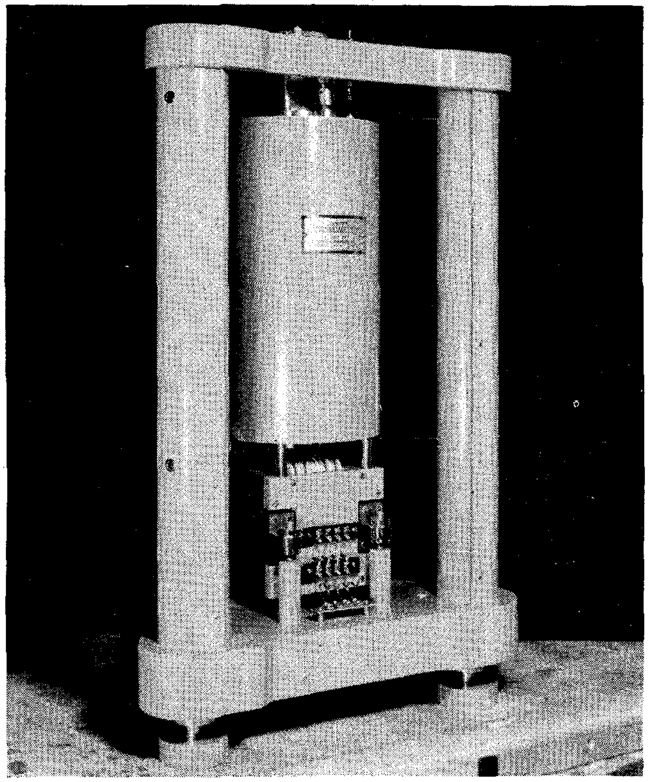

Fig. 2 Vertical component seismometer.

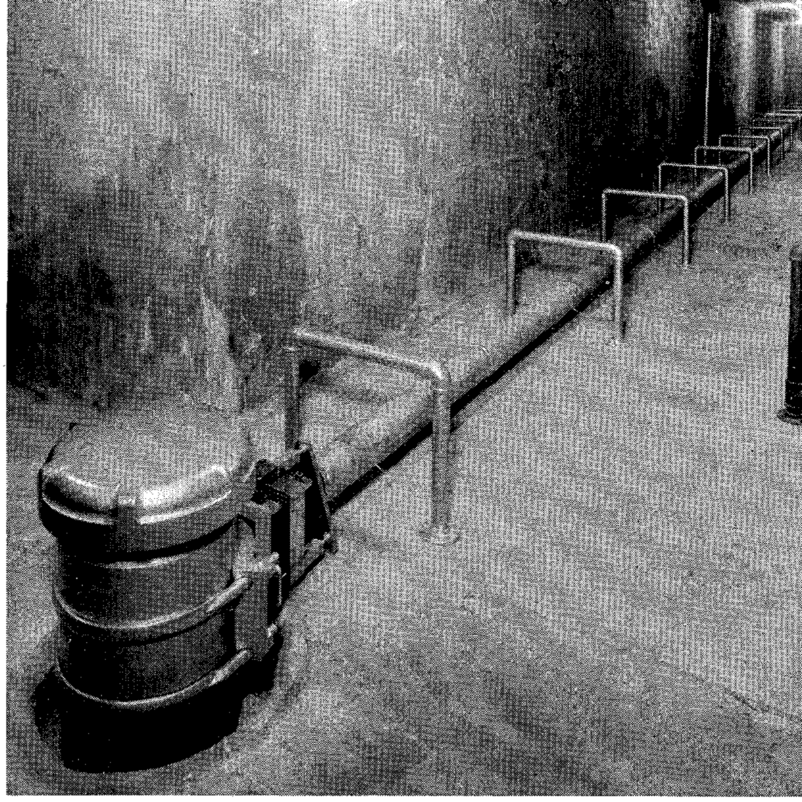

Fig. 4 Electromagnetic linear strain seismograph.

indrical mass. Six steel ribbons are attached to the pendulums in groups of three at each end and to the three supporting posts of the instrument. They serve to confine the pendulum movement to a vertical line. In the horizontal component seismometer, Fig 3, the mass is supported by two of the six constraining ribbons. Restoring force in this unit is provided partly by gravity and partly by the tension of the ribbons. The free period of both the vertical and horizontal component instruments is 1 sec. In practice, each transducer is supplied with two windings for supplying power to two record-

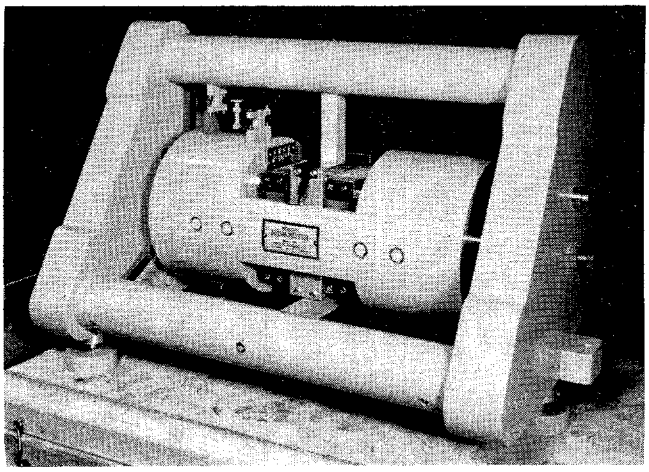

Fig. 3 Horizontal component seismometer.

ing galvanometers operating simultaneously. One galvanometer has a short period (0.25 sec) for covering the high frequency band of the seismic spectrum, whereas the other has a period of from 60 to 90 sec for recording the low frequency portion of the spectrum. With the two galvanometers, each instrument thus covers a frequency range from approximately 5 cycles per sec to 1 cycle in 2 min. The effective magnification of these instruments is limited solely by the ground unrest which is present everywhere on the earth. In regions where the unrest is small, the useful maximum magnification approaches 100,000.

Another new type of seismograph developed at the Seismological Laboratory is the electromagnetic linear strain seismograph. The response of this instrument is derived from strains produced in the ground by seismic waves rather than from the movement of a pendulum as in all other types of seismographs. In effect it consists of two steel piers set into the rock at points 60 feet apart. A 2-in. iron pipe is rigidly fastened to one pier and extends to within a short distance of the other pier. The pipe is supported by 12 wire structures, as shown in Fig. 4, which are longitudinally compliant but quite rigid transversely. When a seismic wave-train traverses the ground in which the instrument is located, the two piers are displaced relative to each other. During a wave compression they approach each other and during a dilatation they recede. This relative movements of the piers produces a motion of the end of the pipe relative to the adjacent pier and serves to actuate a variable reluctance transducer similar to the one previously described. The transducer output power is recorded galvanometrically, as in the seismographs described above. Since the response of this instrument is derived from strains rather than displacements of the ground as is the case with pendulum seismographs, its characteristics differ radically from those of the pendulum instruments. Observations made with this instrument, taken by themselves or in combination with those of pendulum instruments, provide information concerning seismic waves which can not be had from pendulum instruments alone.

The seismograph recording-drums are driven by synchronous motors of special design which operate from impulse currents derived from storage batteries. The impulse frequency is controlled by tuning-forks to a precision of approximately 1 part in 100,000 over a 24-hour interval. The drums rotate once in 15 min. and in a few long-period recorders once in 30 min. The corresponding speed of the paper past the recording light-spot is respectively 1 mm per sec. and 0.5 mm per sec. The storage batteries are charged continuously by rectifiers operating from the power line. The system, therefore, continues to operate for 24 to 48 hours after failure of the line resulting from earthquake or other causes.

Each station of the network is provided with a spring-driven, electrically-wound, marine type of chronometer having electrical contacts which operate once per minute or half minute to actuate time markers on the recorders. In addition, each station has a radio receiver which is automatically turned on seven times daily to record Naval Observatory time signals on the seismograms directly.

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Hugo Benioff, associate professor of seismology, began his scientific work at Mount Wilson Observatory, where he worked summers as an assistant from 1917 until his graduation from Pomona College in 1921. He joined the staff of the Seismological Laboratory, then operated by the Carnegie Institution of Washington, in 1924, after a year at Lick Observatory.

Dr. Benioff's first work at the Laboratory was the development of precise driving systems for seismographic recording drums and a radio timing method for the network of auxiliary stations. Later he developed the variable reluctance electromagnetic pendulum seismograph and the electromagnetic strain seismograph. His seismographs, considered the best available, are operating at stations in all parts of the world.

During the war Dr. Benioff was a research engineer for the Submarine Signal Company of Boston, where he developed numerous sonic, supersonic, and radar devices.

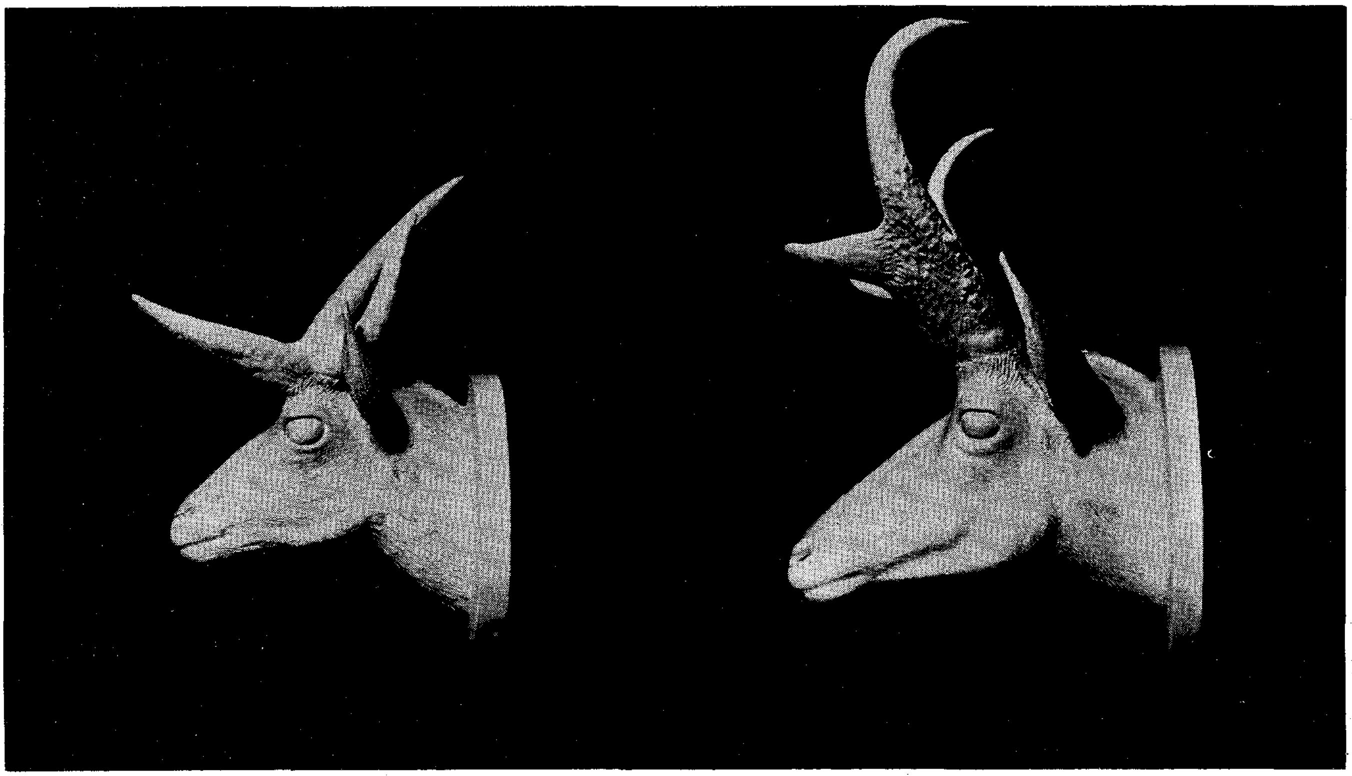

Fig. 6 Restoration of head of extinct 6-horned antelope from the Yepomera Pliocene deposits (on left), and of head of modern pronghorn antelope (on right). Both to the same scale. Restorations by Wm. Otto.

ation of destructive agencies when the organic remains were being transported to their final place of burial, has not yet been determined.

It is apparent from the wealth of material available that the areas immediately adjacent to the lake basin must have been well stocked with animal life. Large herds of horses roamed the country. With these were to be seen on occasion rhinoceroses, the latter representing some of the last of their kind before extinction removed them forever from the native animal world of North America. Smaller herds of camels, antelopes, peccaries, and a few mastodonts give further evidence of the richness of the mammalian assemblage. Large and small carnivores were present, but in fewer numbers, of course, than the herbivores. The hyena-like dogs, known by well-preserved remains at the Panhandle locality, are not so much in evidence in the Mexican assemblage. Small flamingos living in and along the borders of the lake added a picturesque feature to the environment. The remains of flamingos indicate that breeding birds were present at this locality. It is the oldest known occurrence of fossil flamingos in North America.

Only a beginning has been made in the exploration of this part of Chihuahua. The Division of the Geological Sciences plans to continue its geologic and paleontologic studies in the region this year.

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Thus, under good conditions, the progress of a seismic wave across our network of stations can be measured with a precision of approximately 0.1 sec.

Formerly all seismograms were recorded on 12-x36-in. bromide photographic paper sheets. Since some 30 sheets per day are regularly used in the whole network of stations, the cost for paper is rather high. Moreover, the problem of storage of some 10,000 large sheets per year has been serious. To overcome these difficulties, a film-recorder was developed recently for use with 35 mm motion picture film. The resolving power of film is so much greater than that of paper that a single strip 36-in. long serves for a 24-hour record and actually shows more detail than the large paper sheet. The cost of the film is about one-fifth that of the paper and the storage space required is greatly less than that for paper.

Like the surface of the ocean, the earth's surface is never at rest. It is continuously disturbed by waves, the components of which have varying amplitudes, frequencies, and directions of travel. These minute waves are known as microseisms. Some microseisms are man-made, such as those resulting from traffic and explosions. Others are clearly produced by natural causes. In order to study the possible relation between microseisms and atmospheric pressure variations, a microbarograph was developed. The instrument has a conical diaphragm flexibly sealed in the side of a closed cubical box. A coil attached to the diaphragm is immersed in a permanent magnetic field. Fluctuations in atmospheric pressure move the diaphragm and thus induce electric potentials in the coil. The coil is connected to a galvanometric recorder similar to the ones used with the seismographs previously described. The usable sensitivity of this device is limited solely by the residual atmospheric unrest or noise.

It becomes evident from the description of instruments given above that a modern seismological laboratory requires a miscellany of specialized types of recording and timing devices to obtain the fundamental data on which seismological investigations are based. More than that, the task of planning and building these instruments is never completed. As seismological studies progress, the development continues; not only are better devices evolved, but entirely new instruments are created. The limit of this development seems at present to be defined principally by the ingenuity of the creator.