Hydraulic Seismographs.

By S. K. Banerji.

FOR the last three years we have been experimenting on a type of seismographs which have several interesting features. These instruments are based on a method of hydraulic magnification and damping first enunciated by Prof. Kapitza in connection with his experiments on magnetization in very strong magnetic fields. The earlier forms of seismographs constructed on this principle were described in a note in *Nature*, page 547, Vol. 131, 1933; they were not found very satisfactory for the recording of distant earthquakes as owing to their low free periods (about 2 or 3 seconds) and large constraints, they were not sufficiently responsive to slowly varying impulses. They were, however, found to be highly sensitive to quick period movements of the ground, such as would be produced by dropping a weight, or a buried "explosion", and being portable were considered to be a very suitable type of instruments for geo-physical prospecting.

Since writing the above note in *Nature*, the instrument has been considerably improved. The earlier form of the apparatus for the recording of the vertical component of the ground movements consisted of a cylindrical cup whose lower face was closed by a metal diaphragm, and a narrow tube was attached horizontally fitting a small hole in its side, in which a small mirror was suspended from an axle (Fig. 1). A cylindrical jacket covered the cup all round except the diaphragm at the bottom. Some highly viscous oil, such as paraffin or castor oil, was poured into the inner chamber and the diaphragm was then loaded by attaching a weight of about a kilogram or more to a rod passing through its centre. The vertical component of the ground movements sets up oscillations in the membrane and forces the oil to move to and fro through the narrow tube and thus gives a large oscillatory angular motion to the mirror which is recorded photographically.

The apparatus is shown diagrammatically in Fig. 1.

ABCD is the inner chamber, of which the lower face, CD, consists of a thin metal diaphragm of 36 S.G. EFGH represents the outer vessel. T is a narrow tube in which a small mirror M is suspended from a horizontal axis. G is a glass window in the outer vessel to admit light for illumination. A beam of light from a collimator telescope is made to fall on the mirror M and is reflected on a photographic paper wrapped round a recording cylinder. W is the weight attached to the diaphragm. S is a tube through which some viscous oil, such as paraffin or castor oil, is poured and the chamber filled up to a height PQ so that the inner vessel is completely full of oil.

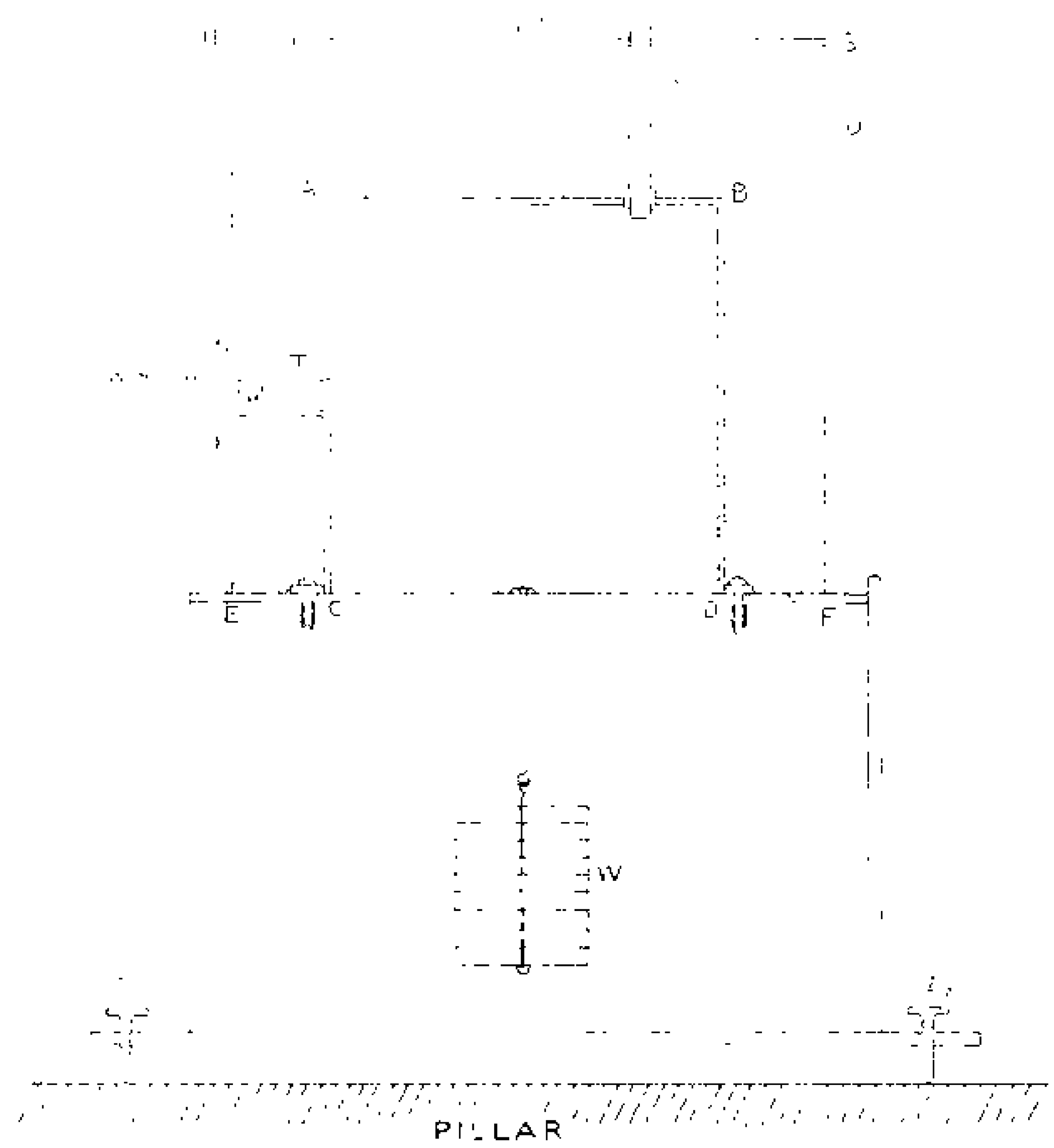


Fig. 1.

When the diaphragm CD moves upwards, the oil is forced out through the narrow tube T, the motion in the tube being magnified in the ratio of the area of the diaphragm to that of the section of the tube. The mirror therefore acquires a large angular motion about a horizontal axis. The whole instrument rests on a cast iron platform with three levelling screws L_1, L_2, L_3.

In one instrument used in these experiments, the following were the constants:—

Diameter of inner vessel	= 15 cm.
Height of inner vessel	= 15 cm.
Diameter of diaphragm (tin)	= 15 cm.
Thickness of diaphragm (tin)	= 0·019 cm.
Diameter of outer vessel	= 23 cm.
Height of outer vessel	= 23 cm.
Diameter of tube	= 1·9 cm.
Weight suspended	= 1 kg.
Mechanical magnification	= 60 times.
Optical magnification	= 10 times.

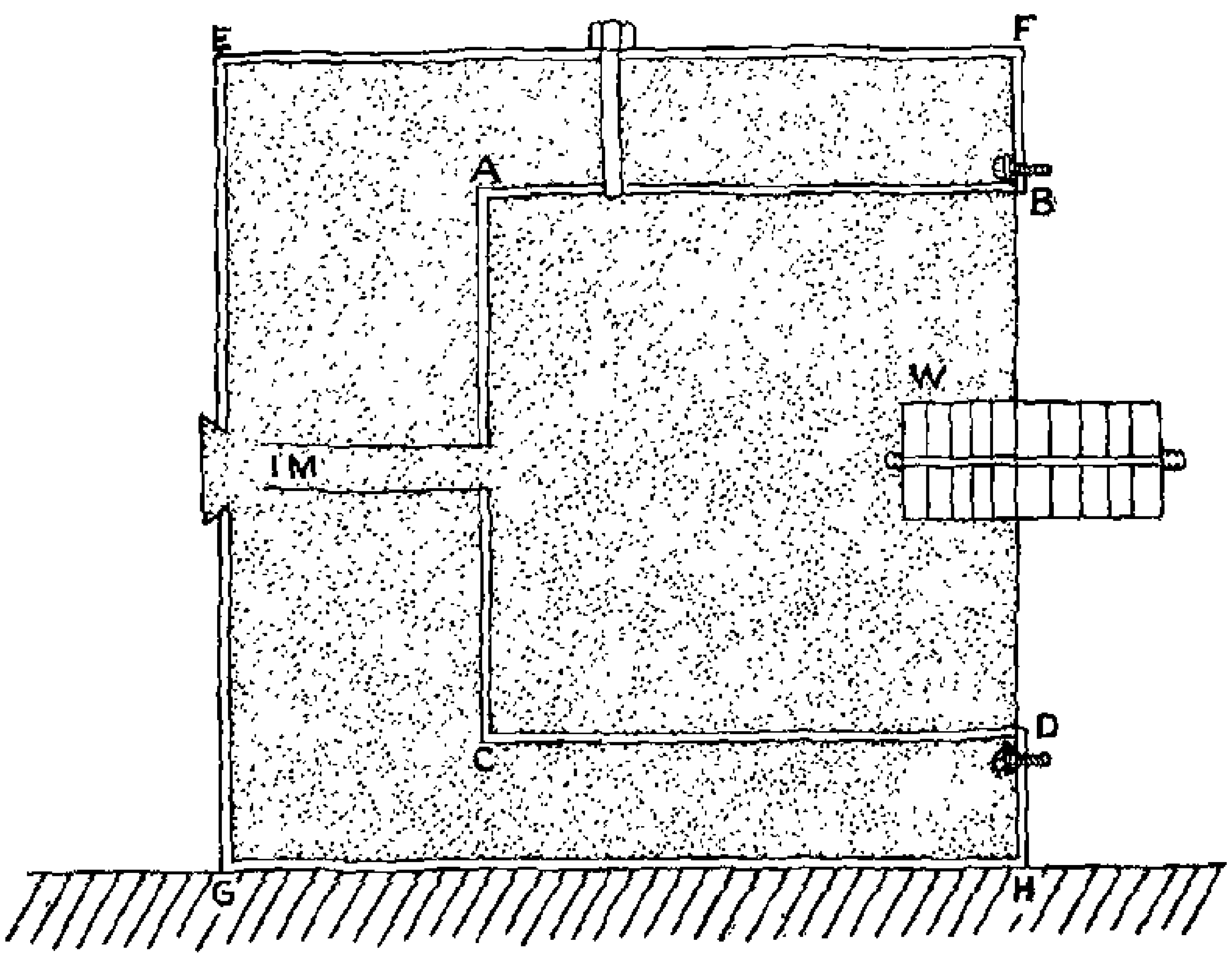
Total magnification	=	600 times.
Period	=	2·3 secs.
Damping ratio	=	5 : 1.

The oil used was castor oil.

Using a brass diaphragm of thickness 0·02 cm., a period of 2·5 secs. and a damping ratio of 5 : 1 was obtained.

If the vessels are of brass, castor oil (even when pure) produces chemical action and it slowly becomes green. To avoid this, the vessels were all nickel-plated.

For illumination, a collimator telescope with a 6-volt straight filament lamp was used. The recording apparatus consisted of a vertical cylinder, of length 6 inches and diameter 6 inches, rotating and at the same time moving vertically downwards along a spiral. The cylinder makes a revolution once every hour and undergoes a downward displacement of about a centimetre during the interval. The speck of light on the photographic paper wrapped round the cylinder traces a spiral. The motion of the recording cylinder down the spiral is controlled by a clock. The motion really occurs under gravity but the clock acts as a brake. As the cylinder rotates in the same direction as the minute hand of the clock, the falling cylinder keeps the clock going. No power is required from the clock, and an ordinary cheap spring-driven clock may be used for the purpose. Time mark is obtained by cutting off the light for 2 or 3 secs. every minute by means of the usual electromagnetic shutter. An instrument of this kind was kept in action for several months. During the period, the instrument gave good records of microseisms but the records of distant earthquakes were not satisfactory. Experiments were therefore made with membranes of other kinds. A leather membrane of diameter 6 inches and thickness 0·06 cm. such as is used in musical drums would increase the period to about 3·2 seconds, and the damping ratio to 7 : 1. The instrument becomes more sensitive to earthquake waves but the "zero" remains unstable until the membrane settles down to some steady conditions. Usually, however, when the instrument is used in this form leaks occur in the membrane after a few weeks' use. The same remarks apply also to rubber membranes. A rubber membrane of diameter 15 cm. and thickness 0·08 cm. gives a period of 3·4 seconds and a damping ratio of 7 : 1. If a membrane of larger diameter is used, the period is increased, but it does not always oscillate in the gravest mode.



PILLAR

Fig. 2.

A similar arrangement was adopted for the recording of horizontal component of the ground movement (Fig. 2). The membrane, BD, is in the vertical plane and is loaded at its centre by two symmetrical weights fixed on either side of a horizontal rod.

The frequency N of a loaded diaphragm with water on one side and a mass m at the centre is given by

$$N = 0 \cdot 4745 \frac{hc}{a^2} \frac{1}{\sqrt{(1+\beta+5m/M)}},$$

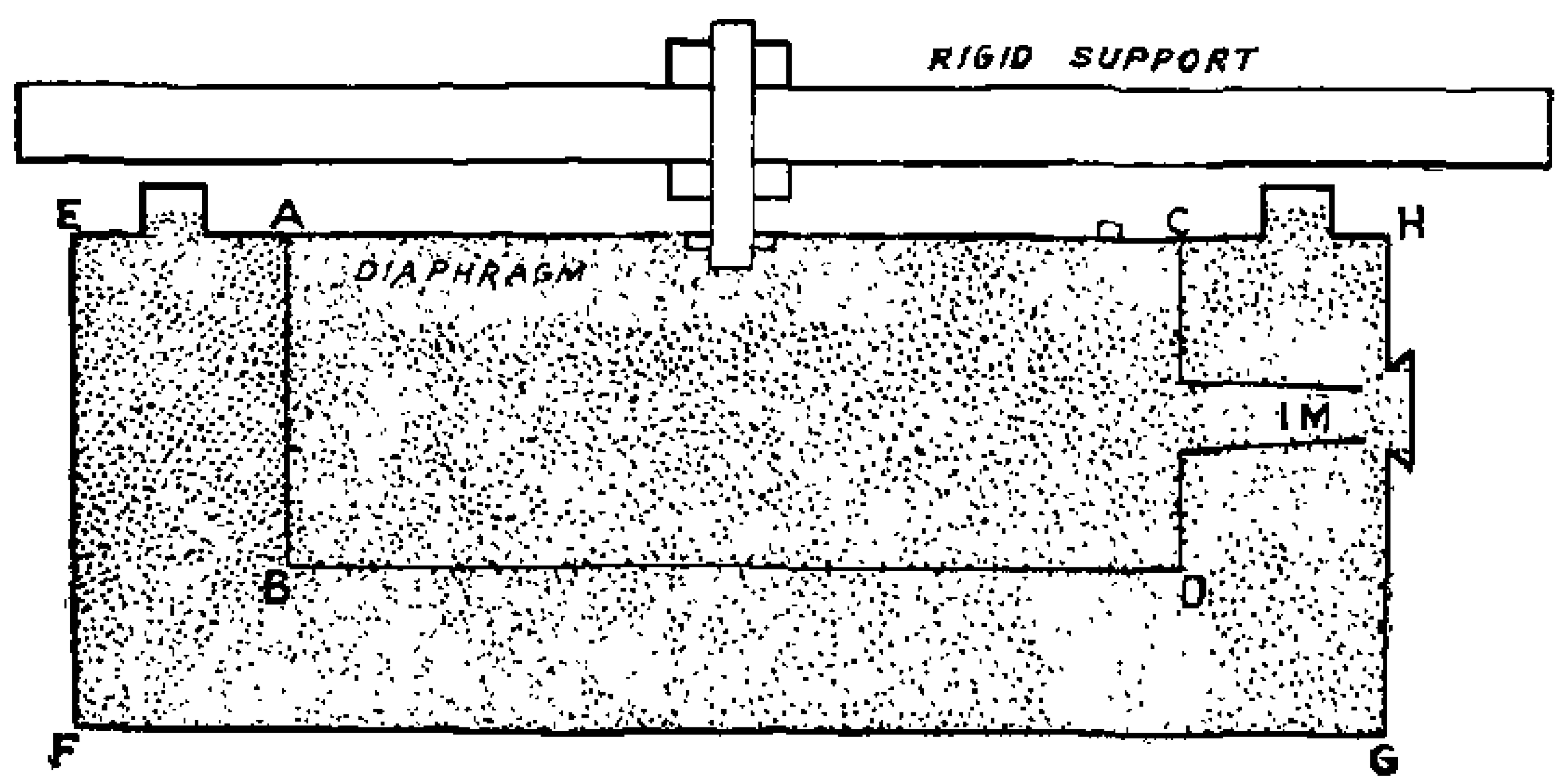
where h is the thickness of the diaphragm, c the velocity of elastic waves in an infinite thin plane of the same material, $\beta = 0 \cdot 668\, \rho' a / \rho h$, ρ' being the density of liquid, ρ density of material of the membrane, m mass suspended from centre of diaphragm and M the mass of the diaphragm. For a rubber membrane, taking $E = 10 \times 10^{11}$ dynes/cm.^{2}, $a = 7 \cdot 5$ cm., $h = 0 \cdot 021$ cm., $\sigma = 0 \cdot 35$, $\rho = 0 \cdot 9$, $\rho' = 1$, $c^2 = E/\rho\,(1-\sigma^2)$, we get the period equal to about 1·5 seconds. The observed period is 3·4 secs. for a rubber membrane of this type. The smaller value given by the above formula is due to its not taking full account of all the physical effects. If we take account of the fluid and its movement into account, then, a more accurate formula for the frequency is

$$N^2 = \frac{1}{4\pi^3 B A^2 \gamma p} \cdot \frac{h^3 d^2}{a^6},$$

where γ = sp. gr. of oil, p = effective length of channel, h = thickness of membrane, d = diameter of opening of mirror tube, a = diameter of the membrane and A and B are two constants. For a seismograph fitted with a brass diaphragm, the data were $h = 0 \cdot 021$ cm., $d = 1 \cdot 9$ cm., $\gamma = 0 \cdot 95$, $A = 0 \cdot 36$, $B = 8 \cdot 77 \times 10^{-14}$ $p_{,} = 2 \times 1 \cdot 75 \times 2 \cdot 54$ cm. The period comes out to be 2·02 secs. This is very nearly the observed period.

The above form of the vertical or horizontal component seismograph is clearly defective. For, there is a limit to the mass which can be suspended from or fixed to the centre of the membrane and this 'mass' is comparable to the weight of the liquid which rests on the membrane. It does not therefore act as a free mass. A "mass" which would remain stationary when an impulse is communicated to the instrument would require to be considerably greater than the weight of the oil. Without a suitable stationary mass, the differential motion (*i.e.*, motion with respect to the stationary mass) communicated to the membrane by ground movement is very small.

In the later models, therefore, the design of the vertical component seismograph was modified to that shown in Fig. 3. In this form the whole instrument, which is suspended from a rigid support by means of a rod attached to the centre of the membrane, AC, acts as a stationary mass. If the support moves vertically downwards or upwards through a distance δx, the centre of the membrane moves through a distance δx and thus forces out or draws in the oil through the tube. In practice this form of the instrument was also found not to work very satisfactorily. This was due to the membrane being strained and assuming a conical shape under the weight which it had to support.



VERTICAL COMPONENT

Fig. 3.

To remedy the above defect the instruments were modified to the forms shown in Figs. 4 and 5. The horizontal component is suspended by a bi filar string from the roof of the building so that the plane of oscillation is in the direction in which the horizontal component is to be recorded. It is found that the best sensitiveness is obtained when the length of the string is such as to give a period equal to the free period

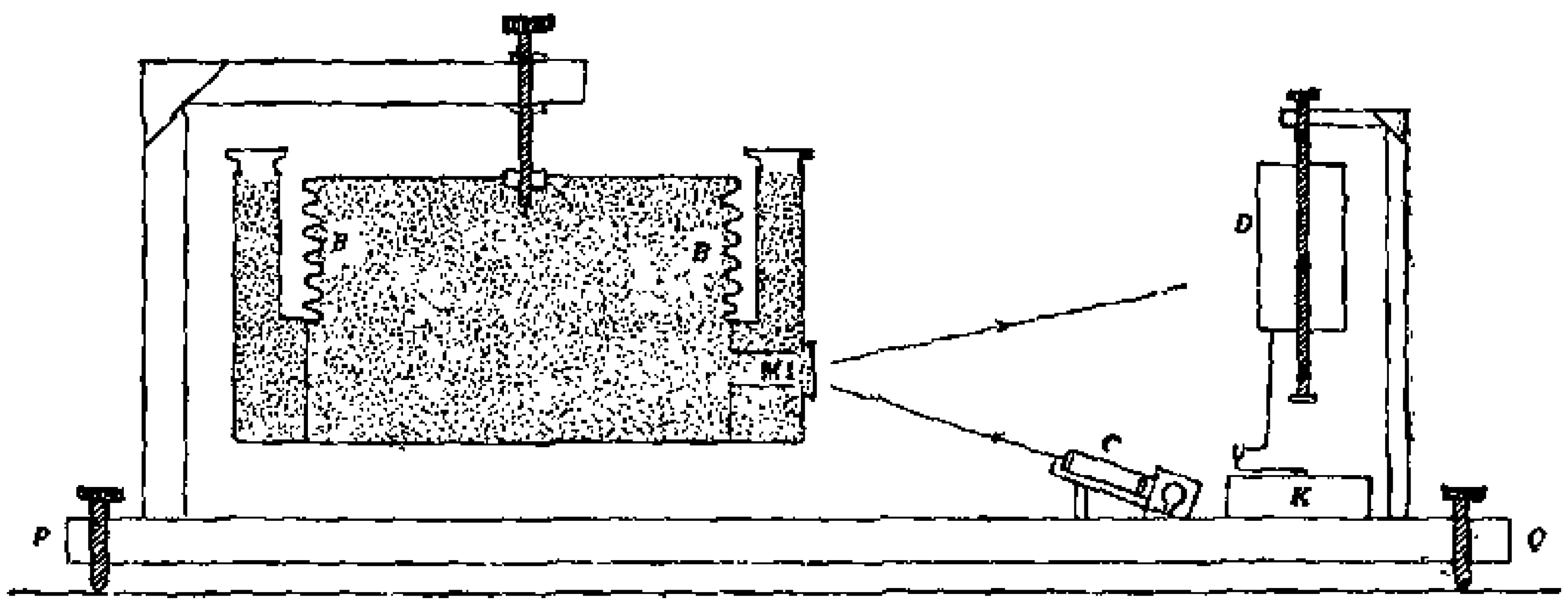


Fig. 4.

Vertical Component.

BB—Flexible Bellows. M—Mirror. C—Collimator Telescope. D—Recording Cylinder. K—Driving Clock. PQ—Cast Iron Stand.

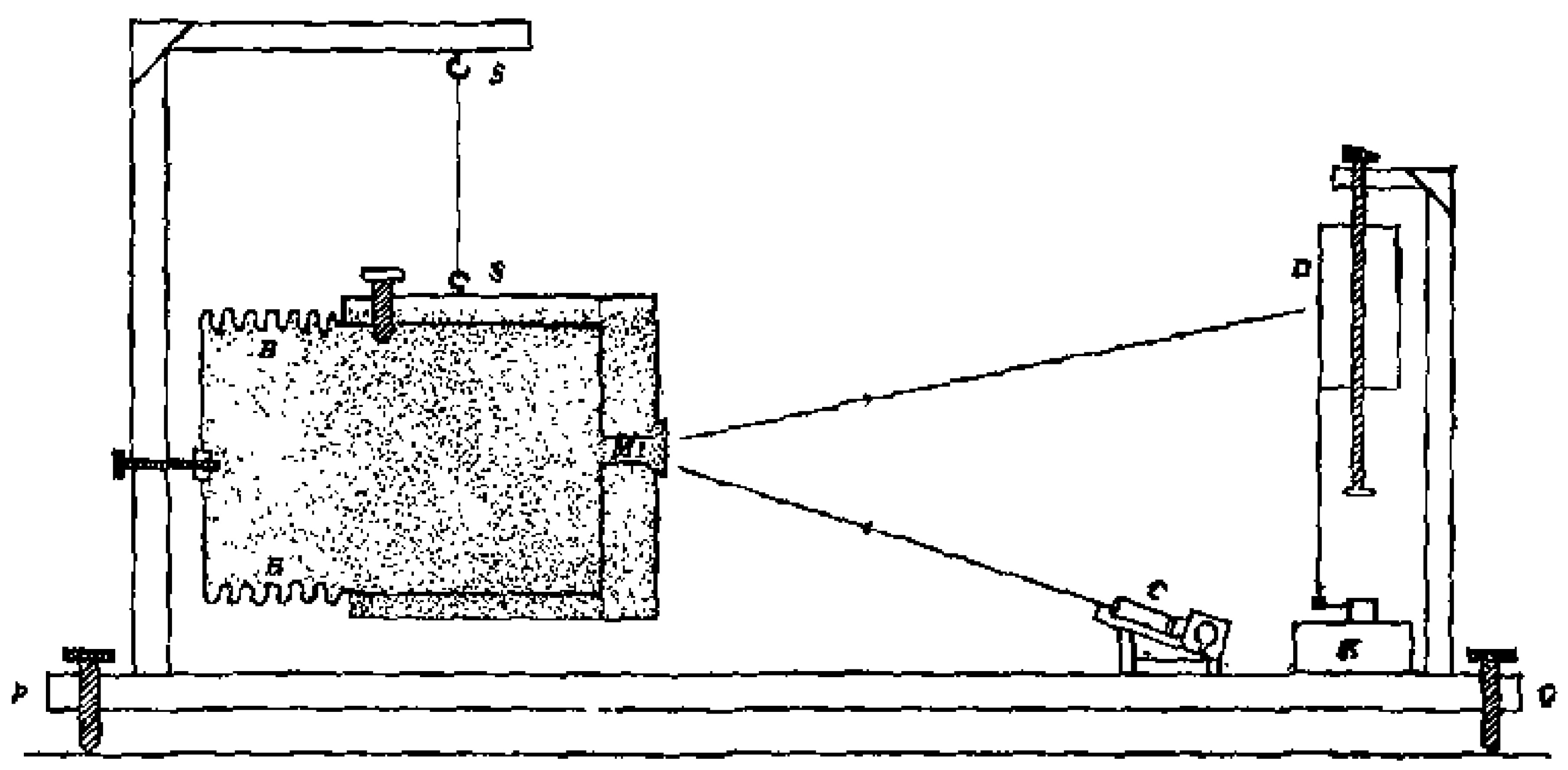


Fig. 5.

Horizontal Component.

BB—Flexible Bellows. M—Mirror. C—Collimator Telescope. SS—Suspension Wire. D—Recording Cylinder. K—Driving Clock. PQ—Cast Iron Stand.

of the membrane. In these instruments the membranes used have cylindrical forms and consequently they undergo no abnormal deformation and retain their elastic afterworking. The most suitable form of membrane for instruments of this type appears to be the flexible bellows (cylindrical), now manufactured on a commercial scale. The preliminary observations made with these modified instruments indicate that they are more sensitive to earthquake movements than the earlier forms.

Fig. 6 is the record of an earthquake and Fig. 7 of microseisms obtained with vertical component hydraulic seismograph.

The chief advantage of an instrument of this type lies in the fact that the parts are all assembled and it can be carried from one place to another and installed in working condition in a short time. Even the most violent movements of the ground cannot displace any of the working parts. The damping ratio can be increased to any desired extent by making the tube in which the mirror is suspended tapering. The calibration of the displacement of the speck of light on the photographic paper in terms of the actual ground movements is readily made by arranging to give specified motions to the platform on which the instrument rests.

The chief defect of the instrument lies in its susceptibility to pressure fluctuation produced by gusts of wind. This effect arises on account of its functioning more or less like an aneroid box. It has been considerably reduced in the latest form of the instrument by making the box (including the oil) as heavy as possible consistent with the elasticity of the membrane, so that the variation in pressure fluctuation becomes negligible compared with the total weight which the membrane has to support. Nevertheless the effect is there and becomes conspicuous when a large magnification is adopted. The effect can be further reduced by installing the instrument in a

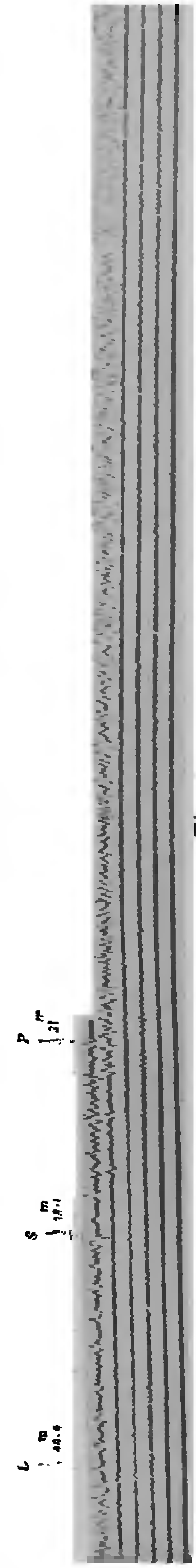


Fig. 6.

Record of an Earthquake by Hydraulic Seismograph (Vertical Component). Distance of Earthquake, 3,600 miles. *The interval between consecutive breaks equals one minute of time.*

Fig. 7.

Record of microseisms by Hydraulic Seismograph, Vertical Component. (The interval *between consecutive breaks equals one minute of time.*)

double-walled room with an air-gap in between which acts as a damper to pressure fluctuations.

The instruments are still in an experimental stage and it is hoped to introduce further improvements in them.

My thanks are due to Mr. K. N. Sohoni who assisted me in taking the earlier series of observations.