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A simplified model of Wood-Anderson Seismograph

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ABSTRACT. A demountable type of Torsion Seismograph based on the principle of the Torsion Seismograph of Wood and Anderson has been described. The model is easy to construct and gives satisfactory results for pendulum periods upto 6 seconds. A few records taken by the instrument are reproduced.

1. Introduction

In order to implement a programme of work connected with the regional study and collection of seismological data in the seismically active regions in and below the Sub-Himalayan belt, the Government of India sanctioned in 1947 a scheme for opening a number of seismological observatories in those regions. The seismic study of these regions became more imperative in view of the many multipurpose schemes for development of water power and irrigation that are proposed to be started soon. The instrument described in the following pages was evolved to give effect to the above mentioned programme. Results so far obtained with it at the seismological observatory, Poona, have been very encouraging and it is considered that it will be quite suitable for study of local earthquakes as well as for recording teleseismic shocks. It is proposed to install in due course a number of these instruments at suitable sites.

The instrument in principle is essentially similar to the Torsion Seismometer described by Wood and Anderson in 1925. They developed a complete theory of the Torsion Seismometer and derived expressions for earth displacement, acceleration and velocity in terms of the seismographic amplitudes. They have also discussed in detail the sensitiveness of the Torsion Seismometer and its relation to efficiency and magnification. The effect of damping on the sensitiveness of the instrument has also been dealt with by them. For details of the theory the original work of Wood and Anderson [1] may be consulted.

2. Description of the instrument

Fig 1 is a diagram of the instrument with cover removed. The back is towards the reader.

A is a solid brass pillar screwed tightly at right-angles to the surface of an L shaped base. The base is a solid casting of gun metal and has three projecting legs, forming the vertices of a right-angled triangle. L_1, L_2 and L_3 are three levelling screws on which the base rests. The pillar A has two projections B and C which have co-axial holes and are provided with side-screws E and F which can clamp the cylindrical heads G and H carrying the pinvices for holding the suspension wire.

A thin tungsten wire of 1/50 mm in diameter and about 16 cm in length is clamped between the two pinvices. This thin suspension carries in its middle eccentrically a thin copper cylinder I, 2.66 mm in diameter and about 3.8 cm long. M is a front-silvered light-weight plane mirror fixed to the top of the cylindrical mass I in such a way that the normal to the mirror is perpendicular to the wire.

The base of the instrument carries another brass pillar P in front of the pillar A. This pillar is meant to carry the table T on which the damping magnet Q with polepieces R is fixed. The table T can be moved up and down without rotation along a guide in the pillar P and can be fixed into any desired position by clamping the screw S. Slow vertical motion of the table T can be made by turning the knurled nut U.

In addition to the oscillations of the suspensions due to an applied angular acceleraation the suspension also sometimes begins to vibrate transversely with very rapid oscillations resembling the oscillations in an excited violin string. To prevent these bow-string vibrations the suspension is made to pass through two oil dampers P_1 and P_2 mounted on the pillar A. The oil dampers can be removed when desired by rotating the dampers about A.

V is a plate vertically fixed to the base, and carries near its middle a lens holder. The lens holder can be moved up and down and can be clamped in any position. The pillars, the suspension and the magnet can be covered by means of the rectangular metal box Z.

Artificial deflections to the suspended system can be given by blowing air at the back of the mirror M through the tube J. The position of the air iet can be adjusted by rotating the tube J or moving it up and down. Controlled deflections in this way can be given to the suspended system even when the cover is on. The system can also be brought to rest quickly when it starts oscillating with large amplitudes.

A front view of the instrument is shown in Fig. 2.

Recording Unit. Recording of the oscillations of the suspension is done photographically employing optical magnification. Two types of recording units have been constructed, one having a drum speed of one rotation in half an hour and giving a paper speed of 16 mm per minute, and another rotating 4 times an hour giving a paper speed of 60 mm per minute. Fig. 3 shows the recording drum with cover removed.

The rotation of the recording drum can be effected by coupling it through suitable gears to either a synchronous motor or a weight-driven governor-controlled clock. Both types of units have been used. A weight-driven governor-controlled clock was specially designed and constructed for this purpose in the departmental workshop and has been found to give satisfactory results. A clock has an advantage over the synchronous motor in that it can be used in non-electrified areas or in areas with DC electric supply. It also maintains more uniform speed. In the case of the synchronous motor small fluctuations in the speed are caused by variations in the frequency of the electric supply.

Photographic paper required for the quick run unit should be 30 cm wide and 92 cm long. It is necessary to use fast paper in order to get a good density on the record. Ordinary bromide papers of normal grade can be used when a 12 watt, straight filament motor car head-light lamp is used as a source of light.

For the slow run unit 9½″ × 19½″ normal bromide paper is used.

3. Light source and Time keeping

The source of light consists of a 12 or 24 watt straight filament motor head-light lamp which can be operated with 6 volts. In front of the straight filament is placed a narrow vertical slit. A light aluminium flag operated by an electromagnetic relay cuts off the light beam from the slit for 2 or 3 seconds. This is achieved by connecting the relay to a 4.5 volts dry cell through an eclipse clock. At each full minute the electric circuit through the relay is completed for about 2 or 3 seconds and the flag is pulled in front of the slit. The bulb, the slit and the relay are all covered by a light tight box having a broad slit in the front panel to allow the passage of light to the seismometer mirror.

The lamp box as a whole can be rotated or moved up and down for adjusting the position of the image on the recorder. A photograph of the lamp box with cover removed is shown in Fig. 4.

4. Setting and Adjustments

Fixing the suspension. The cylindrical heads containing the pinvices for holding the suspension are removed from the holes B and C and the pinvices are unscrewed from them. A thin tungsten wire 1/50 mm in diameter is taken and the free end of the wire from the roll is clamped tightly into the jaws of one of the pinvices. A length of about 16 cm of the wire is then measured from this pinvice and the other end is then clamped tightly into the jaws of the second pinvice. The latter are screwed back into the cylindrical

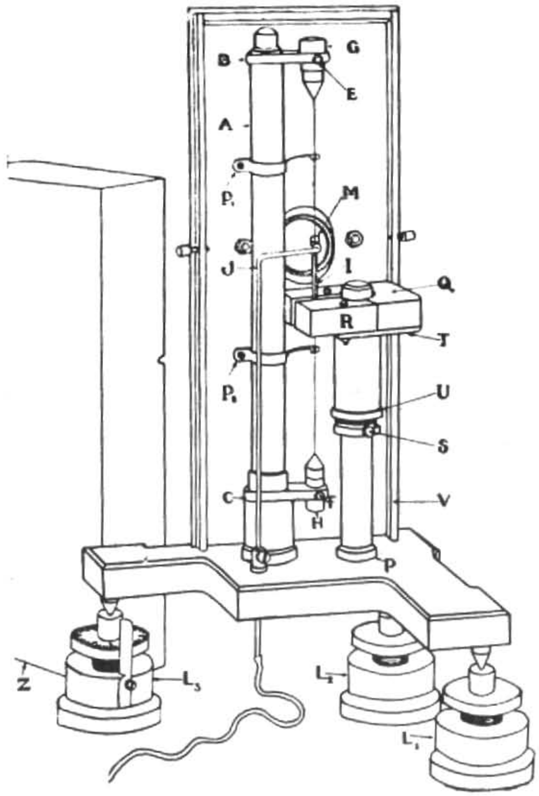

Fig. 1

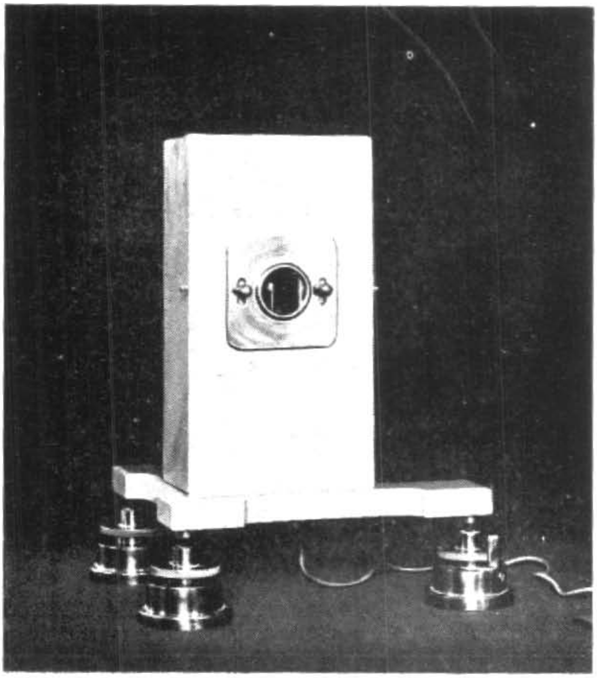

Fig. 2

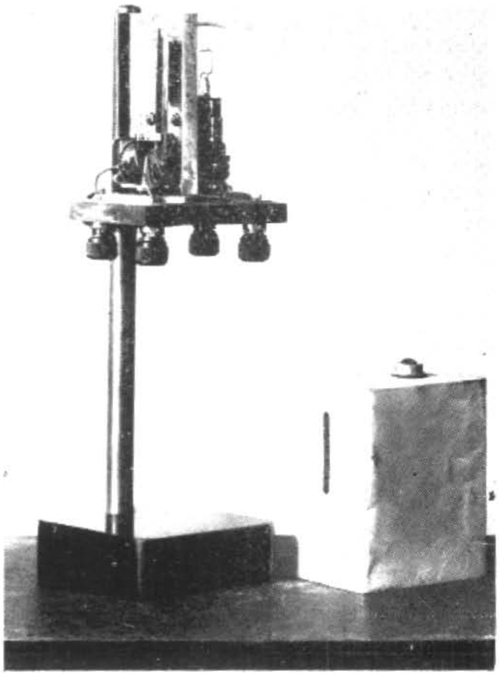

Fig. 4

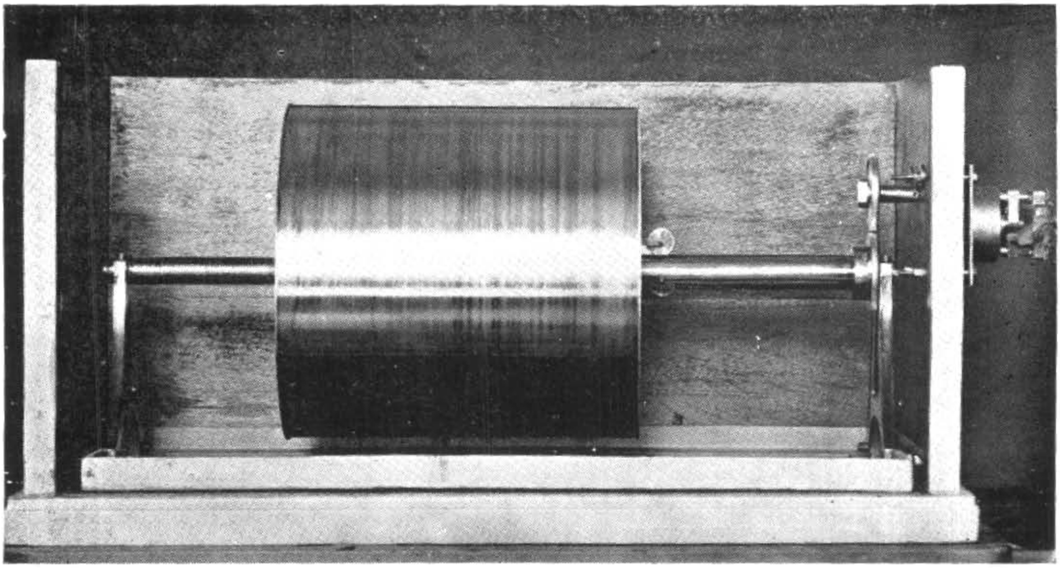

Fig. 3

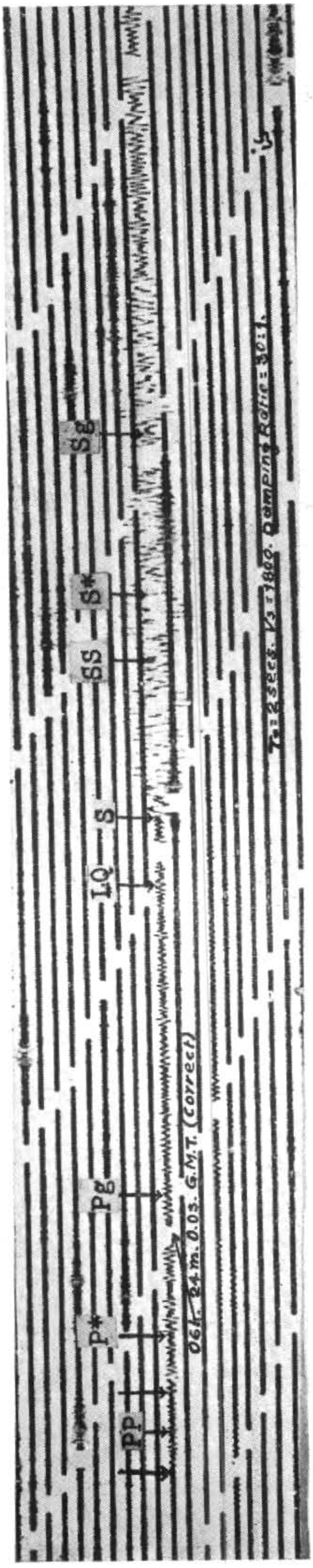
PP
P*
Pg
LQ
S
SS
S*
Sg

Fig. 5 (a)

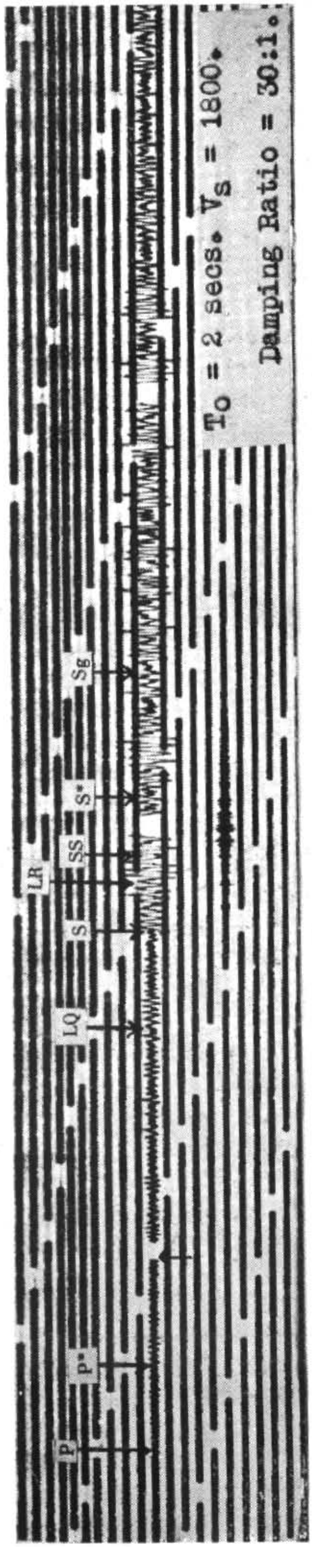
P
P*
LQ
S
LR
SS
S*
Sg
T_o = 2 secs. V_s = 1800.
Damping Ratio = 30:1.

Fig. 5 (b)


07d. 08h. 19m. 2.7s. G.M.T. (Correct)
To=4 Secs. Vs=1100.
Damping Ratio=20:1.
P
PP
sP
S
sS

Fig. 5 (c)

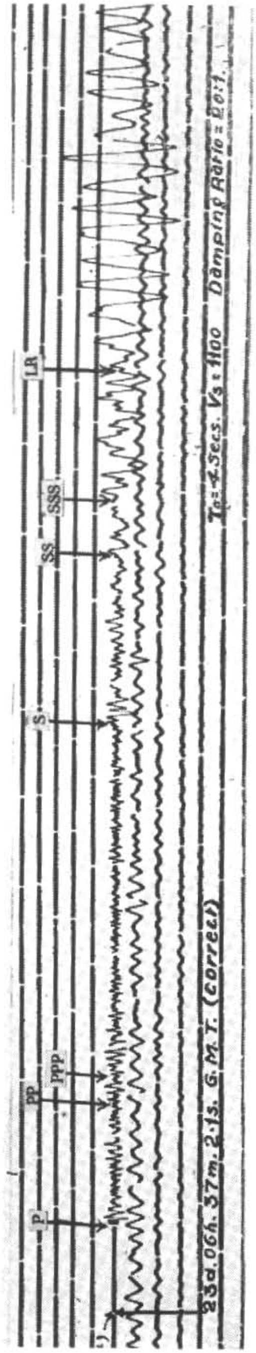
23d. 06h. 37m. 2.1s. G.M.T. (Correct)
To=4 Secs. Vs=1100
Damping Ratio=20:1
P
PP
PPP
S
SS
SSS
LR

Fig. 5 (d)

heads and the whole suspension is slowly introduced into the holes B and C. Levelling of the screws L_1, L_2 and L_3 is done until the lower cylinder hangs freely into the centre of C. The wire is then allowed to untwist for sometime (say an hour or so) and the screws E and F are clamped without allowing the wire to twist. At this stage the instrument is removed from the three levelling screws and allowed to lie flat with plate V and the suspension in a horizontal position. The plate V can be supported at its free end on a wooden block.

A copper cylinder 2.66 mm in diameter* and about 4 cm in length made from pure electrolytic copper (free from traces of ferromagnetic materials) is taken and a thin line parallel to the axis of the cylinder is marked carefully on a lathe. A portion of the upper part of the cylinder (about 2 mm) is filed away such that the normal to the plane surface is at right-angles to line marked on the cylinder surface, and is in the same plane.

The weight, length, mass and diameter of cylinder are next determined accurately and the copper cylinder is treated in turn with dilute nitric acid and alkali to remove any traces of iron that might have stuck on the surface during construction. A thin front silvered plane mirror is fixed to the cut surface of the cylinder with the unsilvered side in contact with copper surface, by means of a dilute solution of shellac in methylated spirit.

After the mirror is rigidly fixed to the mass, the cylinder is horizontally placed on a wooden block on which a V shaped slot has been cut. The position of the cylinder is so adjusted that the line drawn on the surface is on the top. The block is next placed on the plate V such that the marked line on the cylinder is in contact with the taut suspension, and the position of the block is adjusted so as to make the cylinder exactly in the middle of the suspension. A very thin coating of a solution of cellulose in amyl acetate is applied to the surface of contact of the wire and the cylinder by means of a thin painting brush. The wooden block is then removed and the cylinder will remain fixed eccentrically to the suspension. The instrument is then placed back on the three levelling screws.

* The diameter depends upon the value of static magnification desired.

Adjustments. (i) After fixing the suspension and putting the instrument in position it is levelled so that the lower cylinder hangs freely in the hole C. The suspension is allowed to untwist. During this operation it is desirable to raise the magnet table such that the copper mass hangs freely between the pole pieces. When the wire is free from all twists the cylindrical mass should hang between the pole pieces in such a way that small oscillations of the mass about the wire as axis take place at right-angles to the lines of magnetic force. This condition would be achieved approximately if the normal to the mirror is parallel to the lines of force. If this is not so, it can be done by turning the upper cylinder G.

(ii) The magnet table T is then lowered and the cylindrical heads G and H are clamped in position by tightening the screws E and F. As a result of this operation the suspension would get inclined to the vertical and consequently the mirror with the cylinder will rotate through a small angle. The levelling screw L_3 is next turned sufficiently anti-clockwise to make the suspension incline forward. The mirror will consequently oscillate very rapidly. It is now necessary to bring the equilibrium plane of the suspension perpendicular to the line joining the screws L_1 and L_2. This is done as explained in the next para.

(iii) Light from the box is made to fall on the mirror M through the lens and the image of the slit is focussed on the recorder placed at a distance of 1 or 2 metres (depending upon the value of magnification desired). If the pencil of rays is not passing through the centre of the lens it can be made so by adjusting the lens up and down.

The screw L_3 is then turned clock-wise gradually. If the light spot on the recorder shifts from its equilibrium position it is made to come back by raising or lowering the screw L_1. This operation is repeated until raising or lowering of the screw L_3 does not affect the position of equilibrium of the cylindrical mass. In this position the equilibrium plane of the suspended systems becomes at right-angles to the line joining the screws L_1 and L_2. Any desired period can now be obtained by lowering or raising the screw L_3. It may, however, be pointed out that at periods higher than six seconds there is a tendency for the suspended system to become unstable. It is, therefore, not desirable to use a period exceeding six seconds.

(iv) The damping magnet is then raised until the desired value for damping is obtained.

5. Determination of the constants T_0, h and V_s

Free period T_0. The system is allowed to oscillate freely by blowing air lightly through the pipe J and the time of, say, 25 complete oscillations is measured by a stop-watch, from which the free period can be calculated. To have a permanent record, a photographic paper is wrapped on the drum and the free oscillations are recorded photographically with the minute marks. As period depends on amplitude for large oscillations, the value of the deflection during the measurement of periods should be small.

Damping coefficient h. After determination of the free period, the damping magnet is raised and a small portion of the lower part of the suspended mass is allowed to hang freely in the magnetic field. The cover of the instrument is placed in position and a measured deflection of, say, 10 cm is given on one side. If the damping is critical the spot will quickly return to its initial position without performing any oscillations. Normally a damping ratio of more than 20:1 is kept corresponding to a value of $h=0.69$. If the desired damping is not obtained it is done by raising or lowering the magnet by small amounts by turning the nut U. The initial deflections should next be made in the other direction and the damping measured again.

To determine the coefficient of damping accurately and to have a permanent record it is necessary to have a photographic record of the damped oscillations. If the amplitude of the initial deflection and that of the subsequent one on the other side are denoted by A_0 and A_1 respectively the damping coefficient h can be calculated from the formula—

$$h=\frac{\log_{10} A_0/A_1}{\sqrt{1.862+(\log_{10} A_0/A_1)^2}}$$

An average of several measurements is taken for the determination of A_0/A_1.

Static Magnification Vs. The static or geometric magnification in the case of optical registration when the light beam passes through the lens twice is given by the formula $Vs=2L/d$ where L is the distance between the recording surface and the optical centre of the lens and d is the distance of the centre of oscillation of the mass from the axis of rotation. 'd' in this case is equal to $3r/2$ where r is the radius of the copper mass. Since L and r can be measured with sufficient accuracy Vs can easily be calculated in this way.

The value of Vs is also determined in the following way. This method also gives an effective check to the previous adjustments.

The seismometer can be subjected to a small angular tilt ψ at right-angles to plane of equilibrium by applying a constant angular acceleration. This can be effected by slightly raising the screw L_1 or lowering it. As a result of this constant angular acceleration the suspended system is rotated through a small angle θ. It can be shown from a solution of the equation of motion of the system that after the elapse of sufficient time and in the absence of any other acceleration $\theta = \bar{K}\ T_0^2/4\pi^2$, where $\bar{K}$ is the value of the constant angular acceleration. The corresponding linear acceleration will be equal to $\bar{K}d$.

We have, therefore, $\bar{K}d = g\psi$

$$\text{or } d \times \frac{4\pi^2}{T_0^2}\ \theta = g\psi$$

$$\text{or } \theta = \frac{g\psi}{d} \times \frac{T_0^2}{4\pi^2}$$

If A_m is the amplitude of the deflection at a distance L from the optical centre of the lens, then

$$\theta = \frac{A_m}{2L} \quad \text{and} \quad V_s = \frac{2L}{d}$$

$$\text{Hence, we get } \frac{A_m}{2L} = \frac{g\psi}{d} \times \frac{T_0^2}{4\pi^2}$$

$$\text{or } V_s = \frac{A_m}{g\psi} \times \frac{4\pi^2}{T_0^2}$$

If Ω is the pitch of the levelling screw L_1 that is the angle turned in moving the screw by 1 cm and l the distance between the conical legs of the base resting on the levelling screws L_1 and L_2 then it is easy to see that

$$\psi = \frac{\omega}{\Omega l}$$

where, ω is the angle through which L_1 is turned in order to produce a tilt of ψ or the corresponding deflection θ.

The levelling screw L_1 has 55 threads to an inch and the distance l between the screws L_1 and L_2 has been kept during construction to be equal to 8.8 inches, and the head of the screw L_1 is divided into 50 main divisions. If, therefore, the head of the screw L_1 is turned through one division it can be seen that the value of the term

$$\frac{4\pi^2}{g\psi} = \frac{1}{100}$$

The value of A_m multiplied by 100 and divided by T_0^2 would give the value of V_s.

In practice, however, and for purposes of record the value of V_s is obtained by taking a series of observations of A_m with the value of ω in decreasing and increasing orders.

After determining the value of V_s the light spot is brought back to its initial position and the instrument is set for taking records.

6. Calculation of Earth acceleration, velocity and displacement

If A_m is the actual maximum amplitude of vibration measured on the seismogram and a the corresponding maximum earth displacement of the ground at right-angles to the plane of equilibrium, the ratio A_m/a is known as the dynamical magnification. Assuming the earth motion to be of simple harmonic form and the instrument to be critically or nearly critically damped, it was shown by Wood and Anderson that

$$\frac{A_m}{a} = V_s \cdot \frac{1}{M}$$

where $M = \sqrt{(u^2+1)^2+4u^2(h^2-1)}$, $u = T_e/T_0$

T_e, T_0 being the periods of the earth vibration and the free period of the seismometer respectively and h the damping coefficient. The corresponding formulae for the actual maximum earth acceleration α and the velocity v are

$$\frac{A_m}{\alpha} = V_s \cdot \frac{1}{M} \cdot \frac{T_e^2}{4\pi^2}$$

$$\frac{A_m}{v} = V_s \cdot \frac{1}{M} \cdot \frac{T_e}{2\pi}$$

Knowing the values of instrumental constants T_0, h and V_s and the trace amplitude and earth periods from the seisomogram the values of v, α and a can be easily calculated.

Performance

The instrument described above can be adjusted to critical damping conditions within the period range of 1 to 6 seconds, and is, therefore, suitable for recording the true earth motion in a direction perpendicular to the plane of equilibrium. For study of local or near earthquakes it can be set at a period of 1 to 2 seconds and a geometric magnification between 2000 and 3000. It will then register feeble local shocks clearly, which are not generally recorded by large period instruments of low magnification. In this respect its dynamical magnification (for near earthquakes where the range of periods is generally less than 2 seconds), approaches that of sensitive short period electromagnetic seismographs. For the study of distant earthquakes the instrument can be set at periods between 4 and 6 seconds and a geometric magnification of 1000, when it can also register the various long period phases clearly. The instrument has been found to give best results for earthquakes upto a distance of 5 to 6 thousand miles, although records from larger distances are also satisfactory.

The seismometer is easy to construct and can be made in laboratories where ordinary workshop facilities are available. Its constants, unlike the electromagnetic seismographs, can be easily determined and the earth motion can be evaluated accurately.

With a period of one second and geometric magnification of about 1000 it serves as a sensitive vibrograph, and has been used successfully to measure the short period vibrations of dams, buildings, etc. The recording drum in this case is made to run faster by means of suitable gears.

Nearly all sensitive seismographs are susceptible to large temperature change, which has the effect of either crowding the respective traces on the seismogram or separating them far apart. The same effect is observed due to slow tilting of the seismograph pier. This instrument is also no exception and it is necessary to place it in a room free from large temperature variations. In this respect too the effect is much less pronounced than for instruments with longer periods such as in the Milne-Shaw Seismograph, because the sensitivity of an instrument to slow earth tilt is directly proportional to the square of its free period.

7. Records

A few records of earthquakes taken by the Torsion Seismograph described above are given in Fig. 5 (a, b, c and d). Relevant phases are marked on the seismograms.

Fig. 5(a). Record taken at Delhi on 6 April 1949 of an earthquake about 621 miles from Delhi. Small groups of short period vibrations are due to traffic.

Fig. 5(b). Record of a near shock taken at Delhi on 21 April 1949. Distance of the epicentre 450 miles.

Fig. 5(c). Record of a deep focus earthquake taken at Poona on 8 September 1948. Epicentral distance 1300 miles, depth about 150 miles.

Fig. 5(d). Distant shock recorded at Poona on 23 January 1949. Epicentral distance 2480 miles.

8. Acknowledgements

I wish to acknowledge my thanks to the members of the staff of the Seismological Section, Poona, for their co-operation in the work. I am specially indebted to the late Mr. R.G. Bijur, Scientific Assistant, whose help in the construction of the instrument particularly the weight-driven governor-controlled clock was most invaluable.

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