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ROORKEE SEISMOSCOPE

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Abstract

A simplified earthquake recorder, termed as the Roorkee Seismoscope has been developed for earthquake engineering requirement of determining response for idealised dynamic models of structures in those regions where expected acceleration response spectral values are lower than 30% of gravity. The design features of the Roorkee Seismoscope have been discussed in relation to the existing Structural Response Recorder. For smaller accelerations, the new seismoscope would yield more useful records.

Introduction

Specially designed simplified recorders are now finding increased applications in strong motion recording programmes for earthquake engineering requirement of determining spectral response values for idealised dynamic models of structures. The reason for their increased applications are (i) low cost for providing satisfactory instrument coverage and (ii) simple and easy interpretation of records in terms of results, directly usable for design purposes. Most of the records produced by such recorders during earthquakes in India (Agrawal 1969) since the initiation of this programme have been of very small sizes for the reasons that (i) the instrument tilt sensitivity in its present design is low, specially so for the shorter period recorders which are of greater interest in the earthquake engineering applications, (ii) the earthquakes recorded have been of moderate size and (iii) generally the recorders have been located at some distance from the epicentre. These earthquake records have therefore been utilised after making photographic enlargements, resulting in increased error in recorded amplitude measurements. Also, as pointed out earlier by Hudson and Cloud (1967), at such low amplitude the damping due to stylus friction increases. Thus, the contribution due to both the stylus friction and eddy currents caused by permanent magnetic field to give 5% and 10% of critical damping (equivalent) are of the same order at such low amplitudes of motion. This results in large uncertainties in determination of damping values. In the new design of the recorder reported here the stylus friction remains practically same at all amplitudes. Thus it reduces the uncertainty which existed in the previous design and can be usefully employed for obtaining small response values when installed along with the earlier recorder

Description of the Roorkee Seismoscope

Figure—1 shows the Roorkee Seismoscope. This is refered as Structural Response Recorder Model—3 in *Indian Strong Motion Earthquake Recording Programme*. It has a heavy circular base of 26.5 cm diameter. The total height of the instrument with its conical cover is 27 cm (not seen in Figure—1). The cover is fixed to the base by three knurled head screws. A handle is provided at the top of the cover for removing it. The total weight of the recorder is about 3.5 kg. A two legged support is fixed to the recorder base. A gimbal suspension, which can be raised or lowered and fixed to recoder support, holds the pendulum at its upper end retaining it in the vertical position and allowing it to have free motion in any azimuth. By using jewel points in the gimbal suspension the pendulum can be made to have practically undamped motion whereas by using suitable size electroplated steel ball in the gimbal suspension it is possible to obtain equivalent viscous damping in the range 2% to 15%. The variation of damping with amplitude has been studied and it is found to be more at

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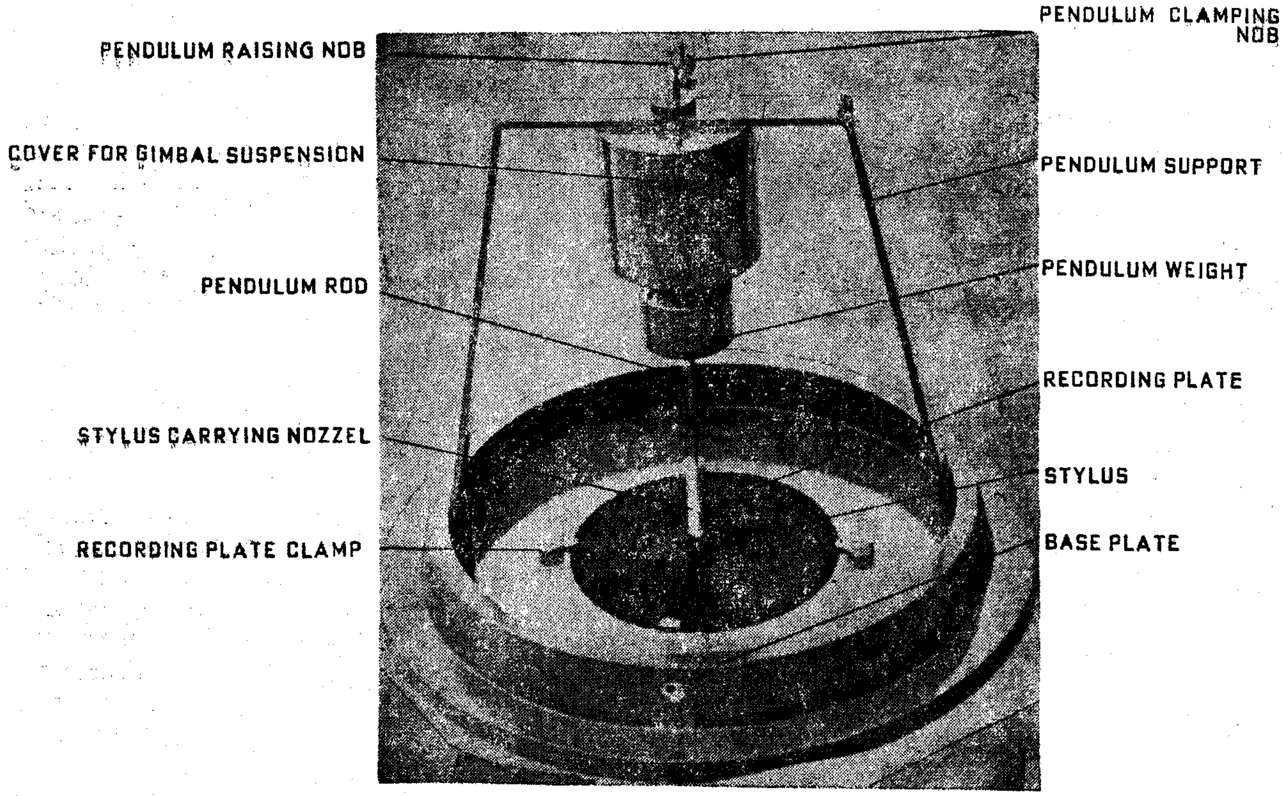

Fig. 1. Roorkee seismoscope (cover removed)

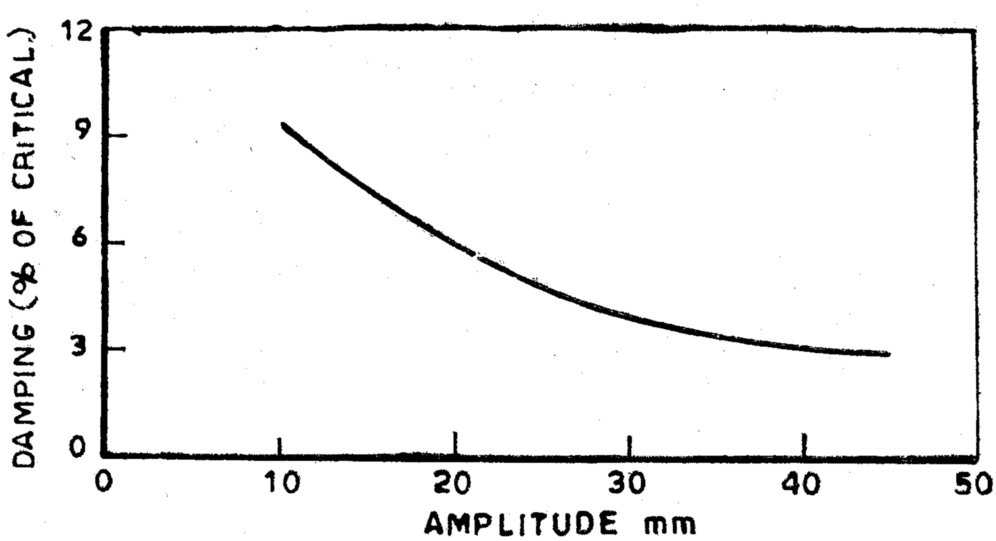

Fig. 2. Variation of damping with amplitude in Roorkee seismoscope

small amplitudes as shown in Figure—2. This variation can be accounted for by calculating damping at the amplitude of recording. At an amplitude of 10 mm which roughly corresponds to small size record of 1 mm on earlier recorder of 0.4 sec period, the damping is easily determinable and does not introduce uncertainties in the results. A protective cover is provided for the gimbal suspension. The pendulum is in the form of a rod carrying a heavy mass as shown in Figure—3. The position of the mass can be raised and lowered for period adjustment. The period is adjustable from 0.4 sec to 0.75 sec retaining the same length of the pendulum in equilibrium condition. The lower end of the pendulum carries a stylus of self adjusting length and scratches a record on the flat circular smoked glass of about 11 cm diameter held in the centre of the base plate. The stylus pressure required for suitable recording is only 1/4 gm. and has a negligible variation with amplitude of recording as the angular deflection for maximum trace amplitude is not large. The entire pendulum assembly could be raised by about 2 cm, bringing the stylus away from the recording plate. This is to avoid scratching of the recording plate while placing it for recording or at the time of removing the record.

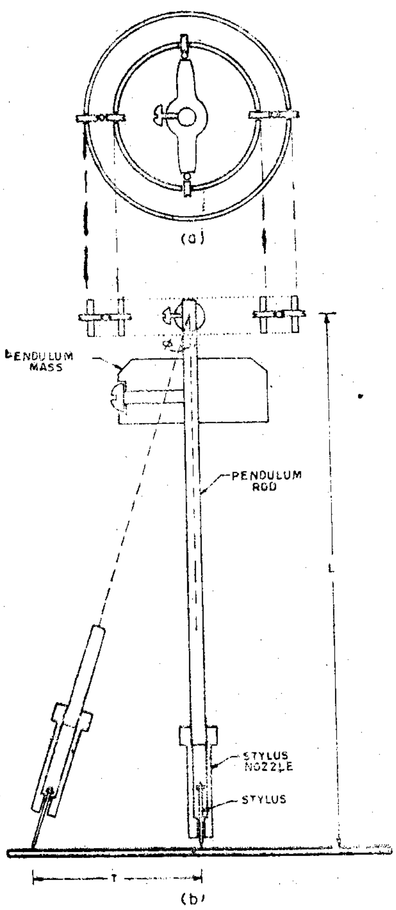

Fig. 3. Sytematic diagram of pendulum, its suspension and stylus.

To avoid water or moisture entering inside the recorder, which may spoil the recording plate, a circular hedging has been provided to the base plate which fits in to the cover. By providing a rubber seal to this hedging and a valve to the cover, the instrument could easily be evacuated aiding satisfactory maintenance of the recorder over long periods.

Dynamic Consideration

The instrument consists of a pendulum with Coulomb damping. Theoretically, the following would be the equation of motion for the system when subjected to an earthquake motion.

$$\ddot{\phi} + n^2\phi + h(\tau) = f(\tau) \qquad (1)$$

where ϕ is the angle of deflection of the pendulum from its position of rest.

n is the frequency.

$h(\tau)$ is the Meander function representing the Coulomb friction A.

$f(\tau)$ is an earthquake function.

The solution of the equation is :—

$$\phi = \phi_0 \operatorname{Cos} nt + \phi_0 \frac{\operatorname{Sin} nt}{n} + \frac{A}{n^2}(1-\operatorname{Cos} nt) + \frac{2A}{n^2}\sum_{k=o}^{n}\left[(-1)^k\left\{1-\operatorname{Cos} n\,(t-kT)\right\}\right] + \int_0^t \frac{1}{n}\operatorname{Sin} n\,(t-\tau)\,f(\tau)\,d\tau \qquad \ldots (2)$$

The first two terms correspond to the homogenous case of free vibrations, the next two to the friction and the last due to the earthquake motion.

Thus, rigorously speaking the present system can not be compared to the single degree of freedom linear viscous damped oscillator used generally to define the response spectrum and if the results of this recorder have to be utilised, a new definition of response spectrum on the basis of equation (2) would be necessary. But the assumption that the system could be considered as mechanical model of single degree of freedom linear viscous damped oscillator for this specific application finds support from following two considerations: (i) The records are to be utilised only to get the maximum deflection and not to obtain the pendulum movement with time, and (ii) the order of damping is very low.

Now let us examine the deviations of the earlier Structural Response Recorder from an ideal single degree of freedom linear viscous damped oscillator. At low amplitudes of motion if small damping was to be introduced then a substantial fraction of damping was due to Coulomb friction. On the other hand at intermediate and large amplitudes non-linear effects due to suspension would become significant. Also, as indicated by Cloud and Hudson (1961) at large amplitudes the damping torque associated with the vertical movement of pendulum would also become effective. Thus, the departures from the single degree of freedom linear viscous damped oscillator and the previous recorder are roughly of the same order as the new system. On the basis of these considerations the response of the Roorkee Seismoscope and the previous recorder were compared by shake table test. On one of the available shake tables two recorders—one of each type calibrated to same period and equivalent damping at average amplitude of records obtained in each case were

Table 1—Shake table seismoscope comparison test results.

	ROORKEE SEISMOSCOPE			PREVIOUS RECORDER		
A	Period 0.40 sec. Damping 5% of critical L* = 15 cm			Period 0.40 sec. Damping 5% of critical, Tilt sensitivity 1.733 cm/radian		
	Double Amplitude (max.) mm	ϕ degrees	Acceleration % of g	Double Amplitude (max.) mm	ϕ degrees	Acceleration % of g
1	93.5	17.28	30.15	10.8	17.88	31.2
2	33.0	6.28	10.95	4.0	6.61	11.5
B	Period 0.75 sec. Damping 5% of critical L = 15 cm			Period 0.75 sec. Damping 5% of critical, Tilt sensitivity 3.623 cm/radian		
	Double Amplitude (max.) mm	ϕ degrees	Acceleration % of g	Double Amplitude (max.) mm	ϕ degrees	Acceleration % of g
1	57.5	10.85	18.9	14.2	11.22	19.5
2	88	16.35	28.5	21.8	17.24	30.0

*Explained under tilt sensitivity.

fixed. A random jerk of suitable intensity was given by hammer impact. The maximum trace amplitudes obtained from both recorders for the same table motion were measured and acceleration response spectral values calculated (Table 1). This was done for 0.40 sec. and 0.75 sec period recorders with 5% of critical damping (equivalent). It is observed that the results from the two types of recorders agree. The utility of the earlier recorder is already established by simultaneous recording of an actual earthquake with strong motion accelerographs. Thus, the new seismoscope giving results equivalent to the earlier recorder is expected to prove satisfactory even in the field use and the records can be utilised as the records of the previous recorder.

Tilt Sensitivity

The most significant advantage of the new seismoscope lies in the higher tilt sensitivity which is independent of the period of the recorder. This is so because the pendulum length is not altered while making period adjustments and only the position of the mass is changed. This would imply that Roorkee Seismoscope would yield large records compared to the previous recorder for the same earthquake motion. However, since the recording is done on a flat glass plate, the sensitivity does not remain constant at all the amplitudes. The values of ϕ can be calculated using following formula (see Figure 3).

$$\phi = \tan^{-1}\left[\frac{T}{L}\right] \qquad (3)$$

where T is the maximum trace amplitude (single) recorded and L is the height of the point of pendulum suspension above the recording plate and is 15 cm in the recorder reported. The calibration for tilt sensitivity in the seismoscope would consist of only measuring the L. The seismoscope described here has reduced range to accommodate a record for acceleration response spectral values upto 30% of g only.

Other Features

Some of the other features of the Roorkee Seismoscope are as follows :

(i) The calibration procedure for the new recorder is much simpler.

(i i) The system is very sturdy compared to the previous design. A strong jerk to to earlier recorder could result in a kink to the suspension thus changing its calibration but can not be so in this seismoscope.

(iii) The instrument can be carried to field with less skill, much ease and installed in less time.

(iv) The possibility of torsional vibrations which caused difficulty due to instability in larger period recorders does not exist is this case.

(v) With considerably smaller stylus pressure which is reasonably uniform upto the amplitudes of interest satisfactory records are obtained. The variation in the stylus pressure introduced greater uncertainty in determining the damping at low amplitudes in earlier recorder.

(vi) The position of the zero reference is easy to determine and single amplitudes can be measured conveniently.