A Simple Instrument for Determining Earthquake Response Spectra

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Synopsis

A simple instrument for recording strong-motion earthquake is described and results obtained with the instrument under test conditions are compared with those obtained by a standard spectrum analysis of accelerograph records. The instrument is made up of a regular seismoscope which is equipped with a time scaling device. From the time scaled record obtained by the instrument, the relative velocity is measured. Using the mathematical model of the instrument the ground motion is determined and the response spectra are calculated by the conventional methods. The simplicity and low cost of the instrument makes it possible to be installed in large numbers in earthquake regions.

Introduction

For the design purpose of earthquake resistant structures it is more desirable to have the ground motion acceleration-time record associated with destructive earthquakes. Such information which is obtained from strong-motion accelerometers is expensive and the process of making the time records is complex. The complexity and high cost of making accelerometer records have made it impossible to provide as complete an area coverage as would be desirable, and hence there has been an incentive for the development of a simpler device which could be installed in relatively large numbers, even though the information obtained might not be as complete as that from true accelerograph.

Seismoscope which was originally designed and constructed by the U.S. Cost and Geodetic Survey does not record either the displacement or acceleration time records, but gives directly a measure of the response of a typical structure to the ground motion. Seismoscope is usually designed to have the same basic dynamic properties of natural period and damping as an average structure and hence can be looked upon as a dynamic model of a typical structure (1). By supplementing the results obtained from a number of the present seismoscopes with information obtained from the existing strong-motion accelerometers, useful information for the design engineer can be made available. However, if the present seismoscopes can be equipped with a time recording device much more useful information can be obtained. With having a time-scaling device on the seismoscope velocity and displacement-time record is obtained. From this time record strong-motion earthquake response spectra can also be determined as shown in this investigation. The response spectra determined in this manner would be much economical than using the common accelerometers.

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Design Characteristics of the Instrument

Details of the instrument will be found in a preceding paper (2), however, the present paper supersedes this earlier paper to the extent that an improved method of interpreting the results is suggested, and more extensive evaluation of overall accuracy can be presented.

The instrument consists of two free conical pendulums which can move in any horizontal direction, being suspended only by a small diameter wire flextrue pivot. The support point of the pendulums acquire the horizontal motion of the ground, and the resulting angular deflection of the pendulums are recorded by a scriber on a spherical smoked glass. Eddy current damping is provided by an aluminum disk which moves between the poles of a strong permanent magnet. Damping can be adjusted by varying the gap between the magnet poles. Both pendulums are supported on the same plate and each of them represents dynamic model of a different structure. The natural periods of T=0.75 sec. and T=0.5 sec. were selected for the pendulums with damping equal to 10% of the critical damping in each pendulum. Natural period of T=0.75 sec. is a typical value for most buildings with eight to ten stories (3); however, natural period of T=0.5 sec. is for small buildings with about five to six stories. A general view of the instrument is shown in Figure 1.

The Time Scaling Device

In order to have time recording of the measurements, a time scaling device is installed on the instrument. The device is basically the mechanism of a regular table clock gear-spring assembly and is mounted on the pendulum support near the stylus arm, as seen from Fig. 1. The gears are so selected that the hammer of the mechanism hits the end of the stylus arm twenty times every second. During a ground motion the stylus scribes a dashed line, instead of a continuous one, on the smoked glass plate as shown in Fig. 2. For comparison, a typical test record without the time Scaling Device is shown in Fig. 2b. The distance between the ends of the two consecutive dash lines in Fig. 2 is 1/20 of the second. The time scaling mechanism is a very simple, inexpensive and self-operated device which can easily be installed on any regular seismoscope with little additional cost.

Spectrum Analysis

To obtain the relative velocity response spectrum from the time scaled record of the instrument, the mathematical model of the instrument is used to obtain the ground acceleration. By using this acceleration the relative velocity response spectrum is calculated (3).

The equations of motion describing the free oscillation of the pendulum are:

$$\sin\phi\,(\ddot{\theta}\,\sin\phi + 2\dot{\theta}\,\phi\,\cos\phi) = 0$$

$$me^2\,\ddot{\phi} + cd^2\,\dot{\phi} + mge\,\sin\phi - me^2\,\dot{\theta}^2\,\sin\phi\,\cos\phi = 0$$

Where:

ϕ = angular deflection with respect to vertical axis
θ = angular deflection on horizontal plane
e = distance from center of mass to the point of pendulum support

d = distance from the end of the pendulum to the point of support

For a given motion to the base of the instrument, the acceleration of the base was recorded by an accelerograph. At the same time the pendulum angular deflection was recorded on the smoked glass plate. The relative velocity response spectra were calculated by using both accelerograph record and the time scaled record of the instrument.

The acceleration time record shown in Fig. 3 was given to the base of the instrument by a special shaker. The velocity response spectrum of this time record and that obtained from the time scaled record of the instrument are shown in Fig. 4. To the extent that these two spectra compares with each other is very encouraging.

One problem in determining the velocity response spectrum by using the instrument is in getting clear time-scaled records. In some strong-motion earthquakes the record on the smoked glass plate is very complicated and the lines are so drawn that it becomes difficult to follow the lines and measure them. Although it is not possible to get complete time record in such cases, by magnifying the pictures of the smoked glass plate it is possible to obtain some part of (mostly from outer lines) the displacement and velocity-time records. Also, by having two pendulums with two different sensitivities, one with high sensitivity and the other with low sensitivity, on this instrument, it is possible to get more clear record at least on one of the smoked glass plates.

Conclusion

The instrument as designed can be a useful device for measurement of strong-motion earthquakes. The timing device on the instrument enables one to get directly the time record of the earthquake events on the glass plate for the study of the vibration of the elastic systems with one degree of freedom, and also make rough estimates of the behavior of real structure. Another advantage of the instrument is that it provides at least partial time record of the ground motion in an earthquake, for a simple calculation of the response spectrum. It is relatively inexpensive compared to the other time recording instruments such as recording accelerographs. The simplicity and low cost of the instrument makes it possible to be installed in relatively large numbers for complete coverage of the earthquake area.

Reference:

1. Cloud, W.K. and Hudson, D.E., "A Simplified Device for Recording Strong Motion Earthquake", Bull. Seis. Soc. Am., 51 (2), p. 159.

2. Sattaripour, A. "Determining Velocity Response Spectrum by the Modified Seismoscope", Proceedings of the Cento Seminar on Earthquake Hazard Minimization, Iran Planning and Budget Organization, Tehran, Iran. 1976.

3. Hudson, D.E. and Housner, G.W.H., "An Analysis of Strong Motion Accelerometer Data from the San Francisco Earthquake of March 22, 1958", Bull. Seis. Amer., vol. 48, No.3, July 1958.

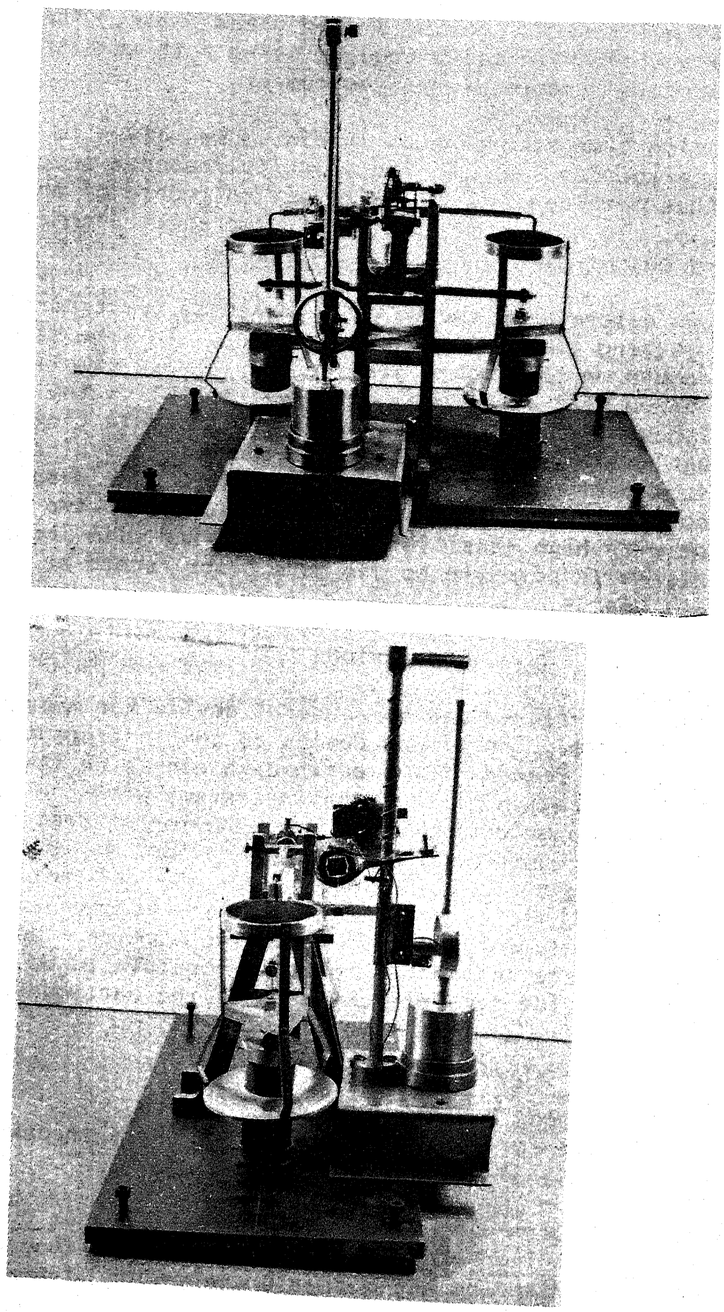

Fig. 1. General Views of the Instrument

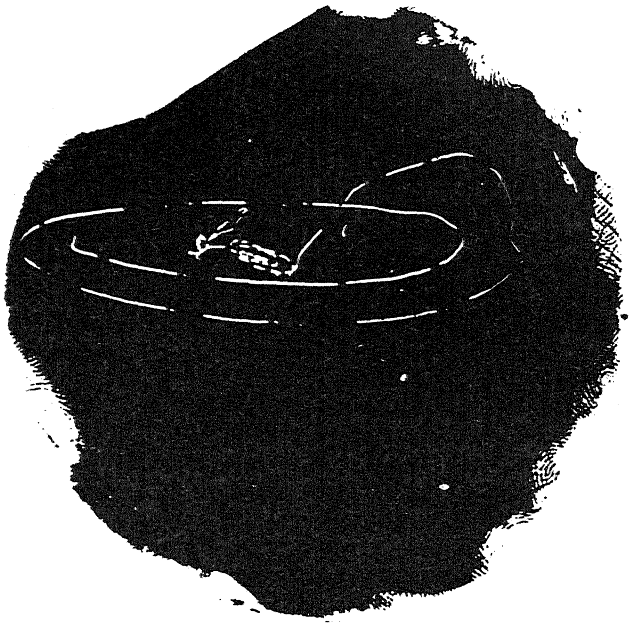

Fig.2 A test record obtained with the time scaling device

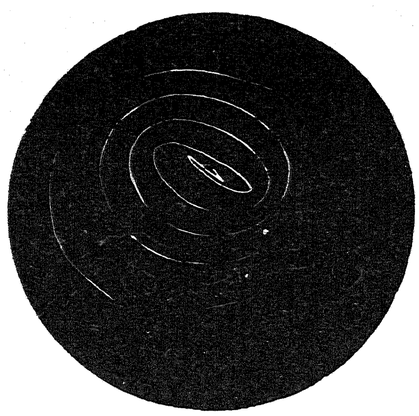

Fig.2b. Test Record obtained without the Time Scaling device

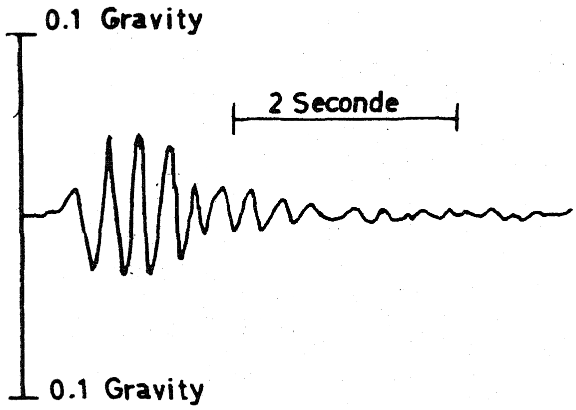

Fig.3:Acceleration given to the base of the instrument

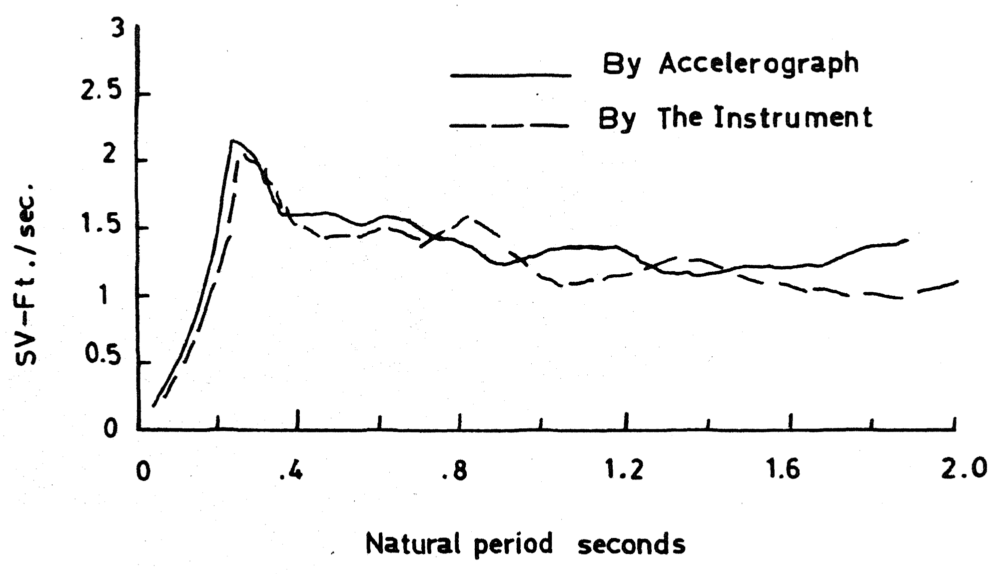

Fig.4: Velocity Response Spectra