of movements. Earthquakes and earth-tremors grade into one another, and in almost every earthquake there is some tilting of the surface. The term “ seismometer ” may con­veniently be extended (and will here be understood) to cover all instruments which are designed to measure move­ments of the ground.

Measurements of earth-movements are of two distinct types. In one type, which is applicable to ordinary earthquakes and earth-tremors, the thing measured is the displacement of a point in the earth’s crust. In the second type, which is applicable to slow tiltings, the thing measured is any change in the plane of the earth’s surface relatively to the vertical. Under Earthquake mention is made of instruments designed by Palmieri and others to register the occurrence of earthquakes, and in some cases to give a general idea of their severity. While some of those instruments act well as seismoscopes, none of them serve to determine with precision the character or the magnitude of the motion. In this article notice will be taken only of instruments intended for exact measurement.

Earthquake displacements are in general vertical as well as horizontal. For the purpose of measurement it is con­venient to treat the vertical component separately, and in some cases to resolve the horizontal motion into two com­ponents at right angles to each other.

*Inertia Method.—*In the first type of measurements what may be called the “ inertia ” method is followed. A mass is suspended with freedom to move in the direction of that component of the earth’s motion which is to be measured. When an impulse occurs the supports move, but the mass is prevented by its inertia from accompanying them. It supplies a steady point, to be used as a standard of reference in determining the extent through which the ground has moved in the direction in question. But, in order that the suspended mass shall not acquire motion when its supports move, one essential condition must be satisfied. Its equilibrium must be neutral, or

nearly so, in order that, when the supports are displaced, little or no force may be brought into operation tending to bring the mass into the same position rela­tive to the supports as it occupied before dis­turbance. This can be made plain by consider­ing the case of a common pendulum hung from a support which is rigidly fixed to the ground.

When the ground moves in any horizontal direc­tion the pendulum’s inertia causes a certain point in it (the centre of percussion) to remain for the instant at rest.

But this contrivance does not yield a steady point, because the sta­bility of the pendulum makes the bob swing down to recover its place directly under the sup­port ; and in fact, if a succession of oscillations of the ground occur, the bob acquires a motion often much greater than the motion of the sup­port itself. This tend­ency may be corrected, and the pendulum made fit to act as a seismo­meter, by any contri­vance which (without introducing friction) will reduce its stability so much as to make the equilibrium of the bob very nearly neutral. In all instruments designed to furnish a steady point the suspended mass must have some small stability,

else it would be unmanageable ; but its period of free oscillation must be much greater than that of the earthquake-motions which it is employed to measure. Even a simple pendulum can have its stability reduced sufficiently to fit it for seismometric work by making it very long. The same result is, however, much more con­veniently achieved by combining a common pendulum with an inverted pendulum placed just beneath it. The common pendulum being stable and the inverted pendulum unstable, if the bobs are jointed so that they must move together, the combination can be made as nearly astatic as may be

desired. @@1 Figs. 1 and 2 illustrate how this combination is applied in seismometry. The stable bob *a,* hung from a fixed support above by three parallel wires, is connected with the inverted pen­dulum *b* by a ball-and-tube joint.

A lever *c*, carried by a gimbal joint in the fixed bracket *d,* is geared also by a ball-and-tube joint to the upper bob. Its long arm carries a jointed index *e,* which projects out and touches a smoked-glass plate *f,* held on a fixed shelf. Any horizontal motion of the ground acts on the lever by the bracket *d,* and causes the index to trace a magnified record on the smoked-glass plate. Fig. 1 is taken from a photograph of an instrument of this kind, constructed to give a much magnified record of small movements. When large earthquakes are to be recorded the mul­tiplying lever is dispensed with, and the index is attached directly to one of the bobs. Observations with instruments of this class exhibit well the very complicated motion which the earth’s surface undergoes during an earthquake. In small earthquakes (such as are only slightly or not at all destructive) the greatest amplitude of motion is often less than a millimetre, and rarely more than a centimetre ; the disturbance nevertheless consists of a multitude of successive movements, quite irregular in amplitude, period, and direction. Fig. 3 is a facsimile of the record given by a duplex pendulum seismograph during one of the earthquakes which occur frequently in the plain of Yedo, Japan. The record, as engraved, is three and a half times the earth’s actual motion.

Instead of two pendulums, a single inverted pen­dulum has been used, with a spring stretched between it and a fixed support above. By ad­justing the spring so that a proper proportion of the weight is borne by it and the remainder by the rigid stem of the pendulum, an approach to neutral equilibrium can be made.@@2 In Forbes’s inverted pendulum seismometer @@3 a somewhat similar plan was adopted : the foot of the pendulum was attached to an elastic wire which tended to restore it to its normal vertical position when displaced.

Another group of instruments designed to furnish two degrees of freedom for the purpose of recording all motions in a horizontal plane, but much less satisfactory on account of their friction, is that in which a rolling sphere either itself supplies inertia or forms a support for a second inertia-giving mass. Probably the earliest was one used in Japan by Dr G. F. Verbeck in 1876 (see fig. 4). On a marble table, ground

plane and carefully levelled, four balls of rock-crystal were placed, carrying a massive block of hard wood. A pencil, sliding in a hole in the block, registered the relative motion of the table and the block on a sheet of paper fixed below. The motion regis­tered is (or would be, if there were no friction) somewhat larger than the true motion of the table, for the system is kinetically equivalent to four upright pieces whose centres of percussion lie in a plane nearly, but not quite, as high as the tops of the balls. This forms what may be Called the steady plane ; its position depends on the relative masses of block and balls, and is easily calculated. When the ground moves in any direction the block moves through a short distance in the opposite direction, and the record is magnified in a fixed ratio. Various forms of rolling-sphere seismometers have been

@@@1 J. A. Ewing, “A Duplex Pendulum Seismometer,” in *Transactions of the Seismological Society of Japan,* vol. v., 1882, p. 89.

@@@2 Ewing, “ A Duplex Pendulum with a Single Bob,’ in *Trans. Seis. Soc. Jap.,* vol. vi., 1883, p. 19.

*@@@3 Report of Brit. Assoc.,* 1841, p. 47, or *Trans. R. S. B.,* xv. p. 219.