SEISMOLOGICAL NOTES.

BY

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I. *A Duplex Pendulum Seismometer.*

The fault of the common pendulum when used as a seismometer is its too great stability. This may be reduced enough to fit the instrument for seismometric work by making the length of the pendulum inordinately great, as was in fact done in the pendulum seismometer which I had the honour to describe to the Society in 1880.* But a very long pendulum presents, in its construction and use, so many difficulties as to be almost impracticable, and methods have been suggested by Mr. Gray † and also by myself ‡ whereby a short pendulum may be brought to a state of neutral or nearly neutral equilibrium. The "Duplex Pendulum" which is now exhibited to the society achieves this result in an entirely new way.

Briefly the idea of the new instrument is this. The common pendulum is stable: an inverted pendulum with pivotted supporting rod is unstable: by placing an inverted pendulum below a common one and connecting the bobs so that any horizontal displacement must be common to both we may make the equilibrium of the jointed system neutral or as feebly stable as may be desired.

The figure shows a vertical section through the instrument. B_1 is the bob of the upper or common pendulum consisting of a hollow cylinder of lead, which is hung by two light wooden rods from a cross piece *c* in which a steel pin is

* *Trans. Seis. Soc. Jap. Vol. I. p. 38.*

† *Trans. Seis. Soc. Jap. Vol. III. p. 145.*

‡ *Ibid. p. 147.*

fixed which stands in a conical cup of agate in the fixed support S_1. This gives the pendulum freedom to oscillate in any azimuth. B_2 is the bob of the lower or inverted pendulum. It is fixed to a stout circular rod *d* which is pivotted to a second fixed support or base S_2 by a somewhat peculiar joint. Two feet *e* fixed to the rod of the inverted pendulum stand respectively in a conical hole and V slot on the upper surface of a steel plate *p*, on the lower surface of which there are another conical hole and V slot in a line at right angles to the line of those on the upper surface. Into the lower hole and V a pair of inverted feet fixed to S_2 press up. The upper and lower slots and Vs are arranged so that their vertices are all in the same horizontal plane. This mode of support also gives freedom to oscillate in any azimuth, and it is employed instead of the more simple method of pivotting a single foot in a single conical hole in order that there may be no freedom on the part of the lower pendulum to rotate about a vertical axis. There is therefore no objection to using a prolongation of the lower pendulum as the indicating pointer. The bobs B_1 and B_2 are connected thus: from a rigid brass bar extending across the top of B_1 there depends a rigid vertical projecting piece ending with a spherical ball which just fits in a cylindrical hole in a tube fixed to B_2. The pendulums therefore move freely together, this joint giving them the necessary power of vertical sliding relatively to each other through a small distance.

The spherical ball on B_1 and the tube on B_2 are placed so that their point of contact is at the centre of percussion of both pendulums. This is the *kinetic* condition which must be fulfilled in order that this point should be the "steady point" when a displacement of the earth occurs. The point of contact is of course a short distance below the centre of gravity of B_1 and above that of B_2.

If for brevity we call W_1 and W_2 the weights of the pendulums referred to this point (that is, the actual weight of each multiplied by the distance of its centre of support from its centre of gravity and divided by the distance of its centre of support from the point of contact between the ball and tube, then the *static* condition which will give neutral equilibrium in very small displacements is that

$$W_1 l_2 = W_2 l_1$$

where l_1 and l_2 are the lengths of the pendulums measured from their point of contact to their respective points of support. In practice a small margin of stability must be given by making $W_1 l_2$ somewhat greater than $W_2 l_1$.

The indicating pointer consists of a light wooden rod *r* forming a prolongation of *d*. At the top of this a light projecting arm is hinged and stands out horizontally with its end (steel-tipped) touching a smoked glass plate *g*. The ratio of multiplication of the record is the distance from the hinge to the lower pivot divided by l_2.

When its equilibrium is nearly neutral the duplex pendulum forms an exceedingly sensitive level. If the line joining the upper with the lower point of support is not perfectly vertical a very large deflection of the pointer results. It is easy to show mathematically that if the equilibrium were exactly neutral when the line joining the supports is vertical the apparatus would be unstable should any deflection of this line from the vertical take place, and that when there is some small stability the effect of such a deflection is to cause a large displacement of the bobs. The same characteristic is however shared by other neutral or nearly neutral equilibrium seismometers, such as the rolling sphere or the horizontal pendulum.

The instrument now shown to the society has been too recently constructed to allow me to give any account of its performance in an actual earthquake, but when tested by means of a shaky table it appears to work very well.

II. *The Suspension of a Horizontal Pendulum.*

The method of support hitherto adopted in my horizontal lever seismometers has been to use a rigid frame pivotted by joints at two points nearly in the same vertical line. In place of joints we may use flexible connections, since the actual angular displacement is never large, just as in clock pendulums a spring suspension is commonly used in place of a hinged joint. Mr. Gray has described a modification of the horizontal lever called by him a conical pendulum seismometer, in which the frame of the lever is reduced to a single strut and tie, the strut being set horizontally with its end jointed to a fixed support and the tie consisting of a wire fixed at its upper end, so that its flexibility and torsional elasticity make it serve as a substitute for a second joint. Recently I have gone a step further, and have introduced a flexible spring or wire in place of the other joint also. To do this it is only necessary to fork the strut and carry it out beyond the vertical axis of support and then tie it back to the axis by a flexible spring, preferably a steel band with its flat side vertical. The wire tie intersects the vertical line through the centre of gravity of the mass at a point horizontally in front of the lower point of support to which a prolongation of the strut at the back is tied by a flat steel band. A fixed pin sliding freely in a slot on the strut is added to prevent any bodily translation of the strut to one side or other during an earthquake, and hence the hanging mass has no other freedom than that of rotation about the nearly vertical line joining the upper and lower points of attachment. So far as can be judged by recent experiments this arrangement offers less frictional resistance than the method of support by pivots, and any change which gives a diminution of friction is an improvement in a seismometer.

III. *A Speed Governor for Seismograph Clocks.*

The fluid friction governor shown to the society on a former occasion possessed the defect that the balls (whose centrifugal displacement caused fans to be immersed more or less deeply in a trough of oil) were liable to be disturbed by an earthquake, so that the action of the governor became to some extent irregular at the very time when uniformity of speed was most necessary. A modified form which has been recently applied to the clock of the seismograph in Tokio University overcomes this difficulty successfully. Instead of two balls two pairs of balls are used, fixed at the ends of links which cross the spindle X-wise. The upper ends of the links also carry the fans whose immersion in oil checks the speed. A pair of springs resists the centrifugal tendency of the balls. The centre of gravity of each link with its attached balls coincides with the joint between it and the spindle, and consequently the shaking of the clock during an earthquake produces no change in the configuration of the governor. The effect of an earthquake on the oil in the trough is immaterial, both in this and in the older form.