A NEW FORM OF PENDULUM SEISMOGRAPH.

By J. A. Ewing, B.Sc., F.R.S.E.,

Professor of Mechanical Engineering in the University of Tokio.

(Read April 26th, 1880.)

The object of the present paper is to describe a seismograph of the author's design, which has been erected in the university of Tokio. The instrument is intended to register graphically the horizontal movement of a point on the earth's surface during the whole of any seismic disturbance. For this purpose two continuous curves are automatically drawn, showing on a greatly magnified scale the extent of displacement in two directions at right angles to each other, in conjunction with the time. From these it is easy to determine the total movement at any time during the disturbance, its direction and its velocity.

The instrument consists of a long pendulum having a massive bob with which the short ends of two multiplying levers are kept in contact. The fulcrums of the levers, being rigidly connected to the earth, move with it, and (on the assumption that the bob of the pendulum remains at rest) their long ends will move through distances which are certain multiples of the component displacements of the earth's surace. The levers are placed at right angles to each other and are so arranged that each is affected only by the component displacement in its own direction. The long end of each lever is in contact with a smoked glass plate which is revolved continuously by clockwork. When an earthquake takes place the levers move out and in along the radii of the glass plates, and thus curves are drawn, showing the relation of displacement to time in two directions, throughout the whole disturbance.

The bob of a pendulum used as a seismometer is liable to be set in motion during an earthquake by either of two causes. First, by the resistance of the recording apparatus due to friction and inertia, and second, by the motion of the point of support, and the consequent effect of gravity upon the bob.

To avoid as far as possible the first of these disturbing causes, the recording lever should be made exceedingly light, relatively to the mass of the bob, and the friction both at the fulcrum and at the recording point should be made as small as may be consistent with definiteness of support and distinctness of record.

Moreover, it is of the greatest importance that the point of contact between the recording lever and the bob should be as near the centre of gravity of the latter as possible, or at least that the line of action of the resistance to motion of the recording lever should pass through the centre of gravity of the bob. Otherwise a motion of the bob, not as a whole, but of one part relatively to another, will be induced. In some of the author's earlier experiments a spherical bob was used and the recording lever was kept in contact with the foot of it. It was found that a sudden displacement of the fulcrum of the lever produced a rotation of the bob about a horizontal axis, which, although the recording lever offered very little resistance to motion, was sufficient to completely falsify the record. In the instrument as it now exists, the bob acquires no sensible motion of any kind on account of the resistance of the recording apparatus.

The second of the two causes of disturbance mentioned above will be excessively great if at any time during the shock the point of suspension of the pendulum makes its oscillations in times equal to or multiples of the periodic time of the pendulum, but will be felt only very slightly if the period of the pendulum is greatly in excess of that of the motion of the point of suspension. Little is as yet known of the length of time occupied in each oscillation of a point on the earth during an earthquake, but it is probably only a fraction of a second in most cases. If, therefore, the point of suspension could be connected quite rigidly to the surface of the earth, all sensible error due to this cause might be avoided by the use of a sufficiently long pendulum. It is, however, a matter of experience that even very long pendulums when hung from the roofs or walls of buildings do acquire a swing often of great amplitude during earthquake shocks. This is no doubt due to the fact that their supports are neither sufficiently free to avoid being thrown into oscillation nor sufficiently rigid to partake simply of the motion of the earth itself.

In the instrument now to be described the pendulum is of great length, and it is supported by a very strong and stiff wooden framework, securely founded in the earth, and entirely disconnected from the building in which it is placed, so as to be uninfluenced by wind, unequal heating by the sun's rays, or other causes.

By making the pendulum long, its supporting framework stiff, and the recording indices exceedingly mobile, it has been attempted to reduce to the smallest possible amount the causes of disturbance just mentioned. As, however, it is impossible to secure that the bob shall remain absolutely at rest during a shock, this seismograph has been designed so that any small swing acquired by the bob will be distinctly shown in the diagrams and be easily separable from the earthquake motion proper. With this view the pendulum has been made twenty-one feet long, so that its natural period of (complete) oscillation is very nearly five seconds. This period is probably much longer than is needed to prevent the period of the pendulum from agreeing with that of the motion of the point of suspension, but it has the advantage that, if the pendulum acquire a swing during an earthquake, its motion will produce a curve of great wave-length in the record, and on this the actual earthquake motions will be superposed in short waves which can be distinguished without difficulty from the long wave due to the swing, and have their amplitudes and

Pendulum Seismograph

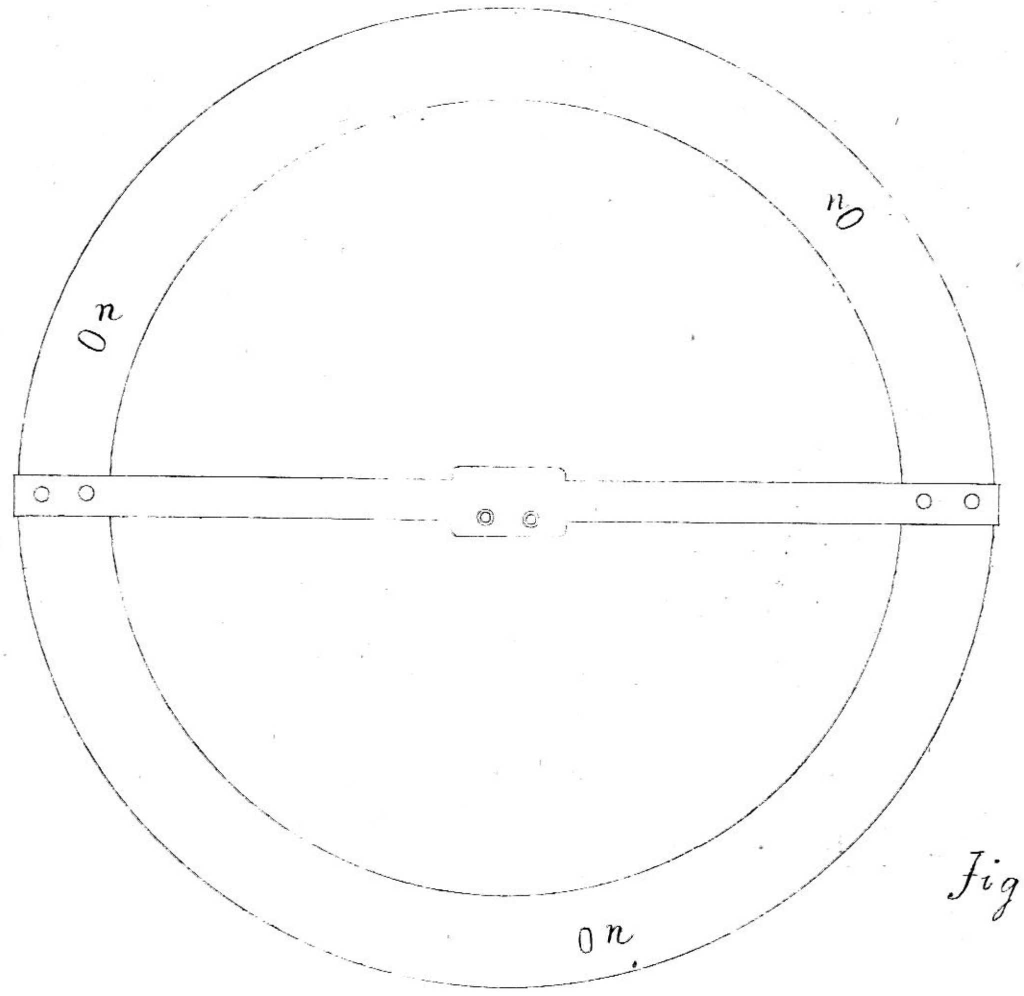


Fig 1.

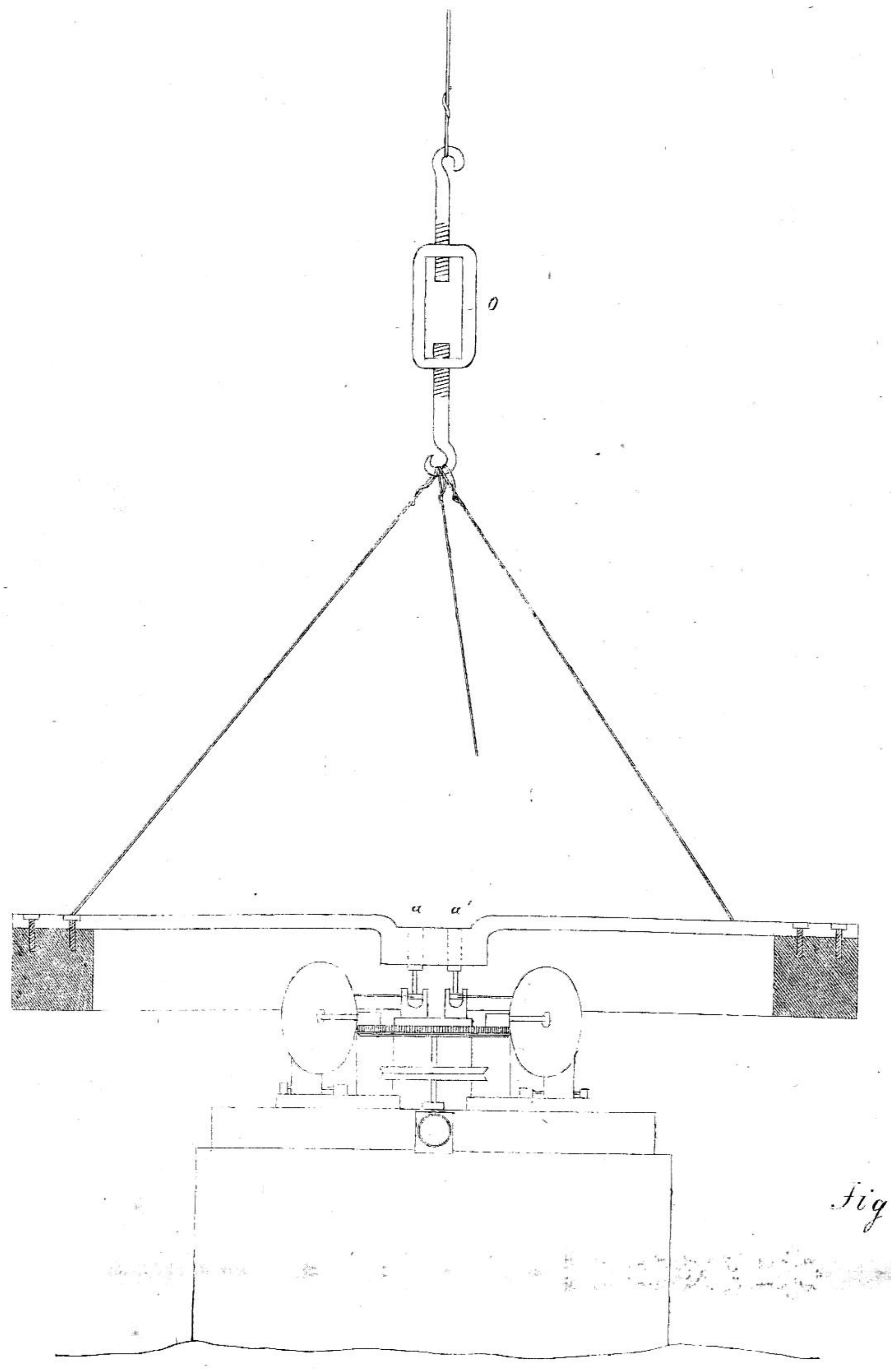


Fig 2.

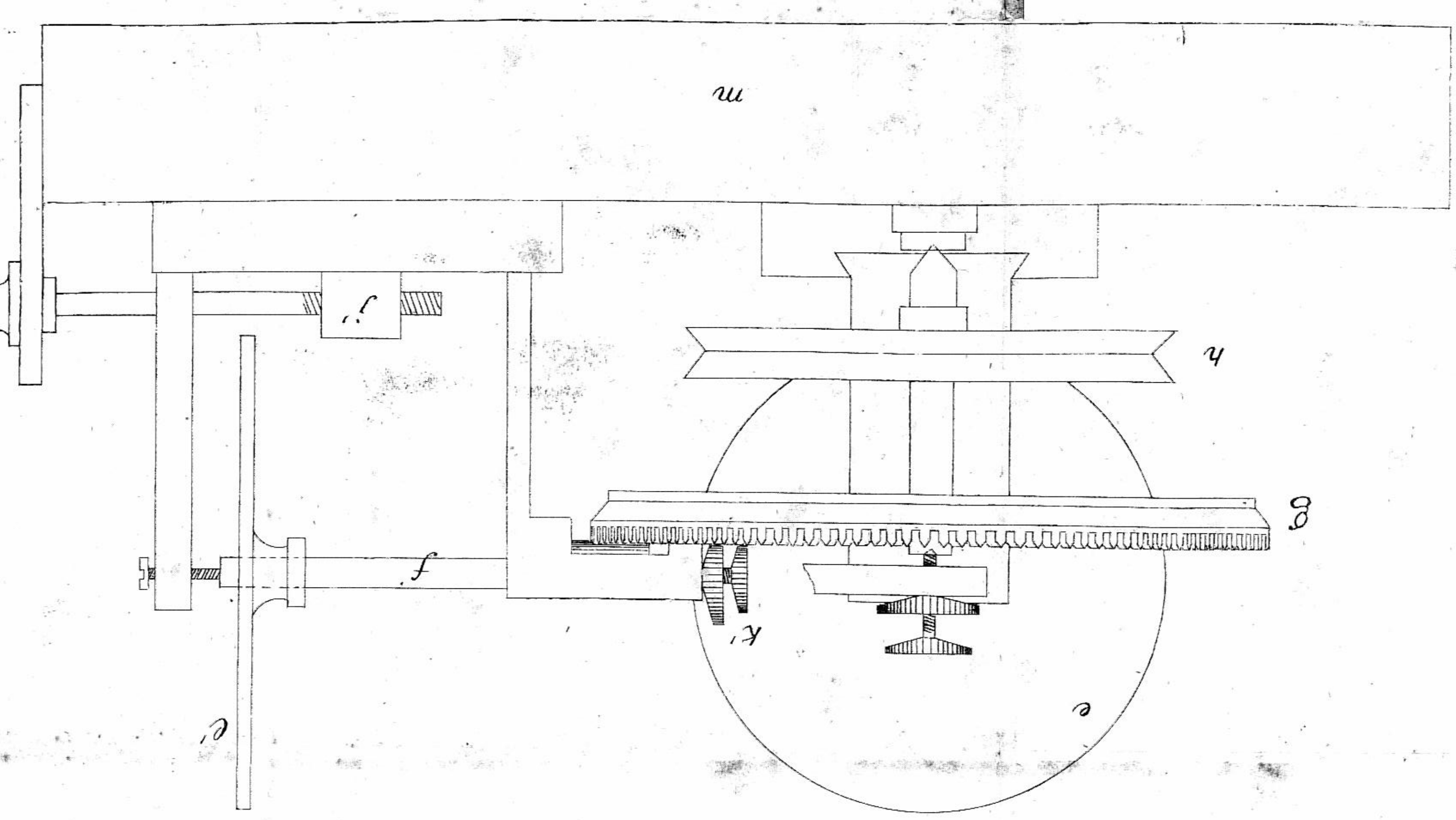


Fig 5. Full size.

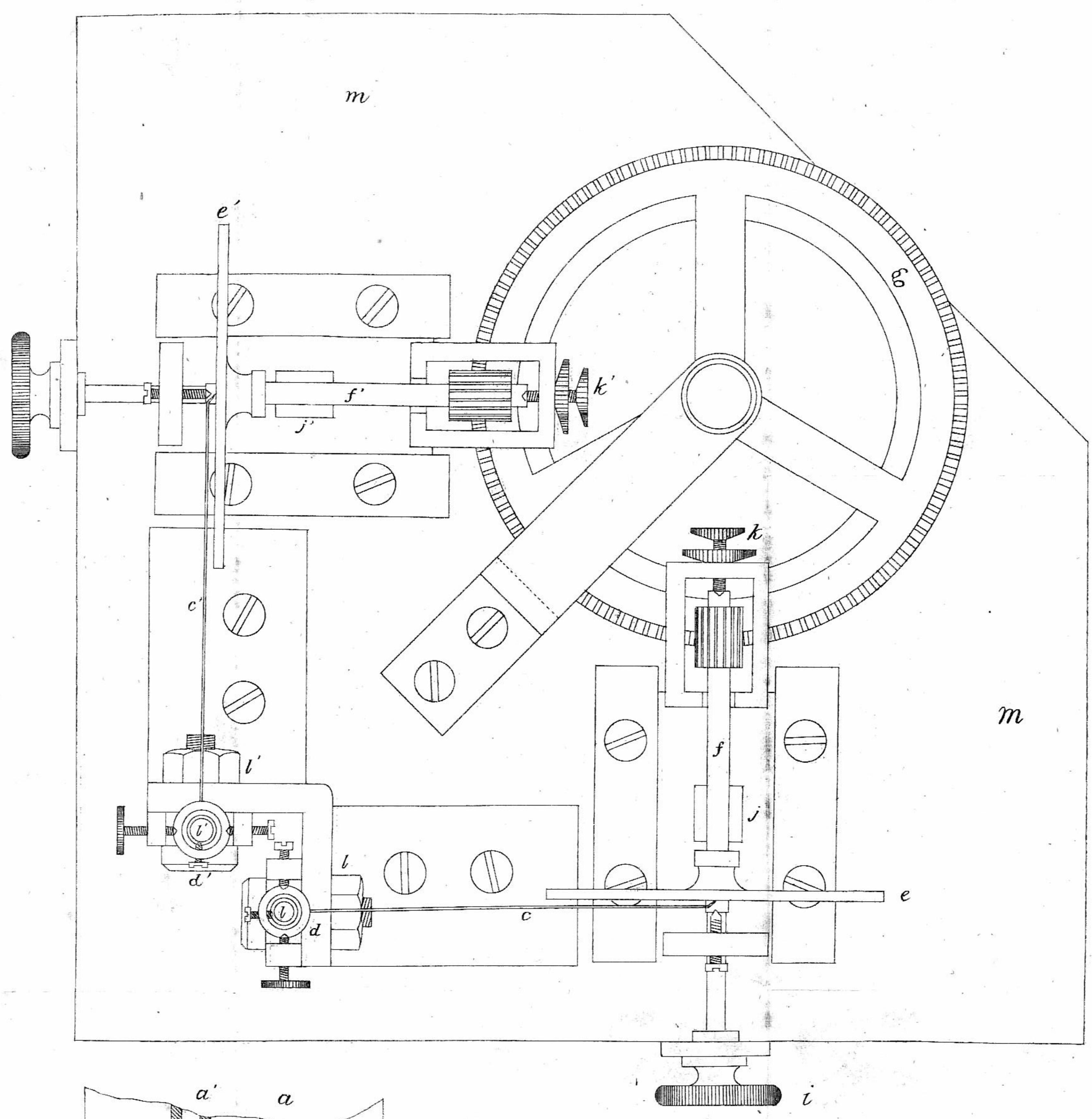


Fig 3. Full size.

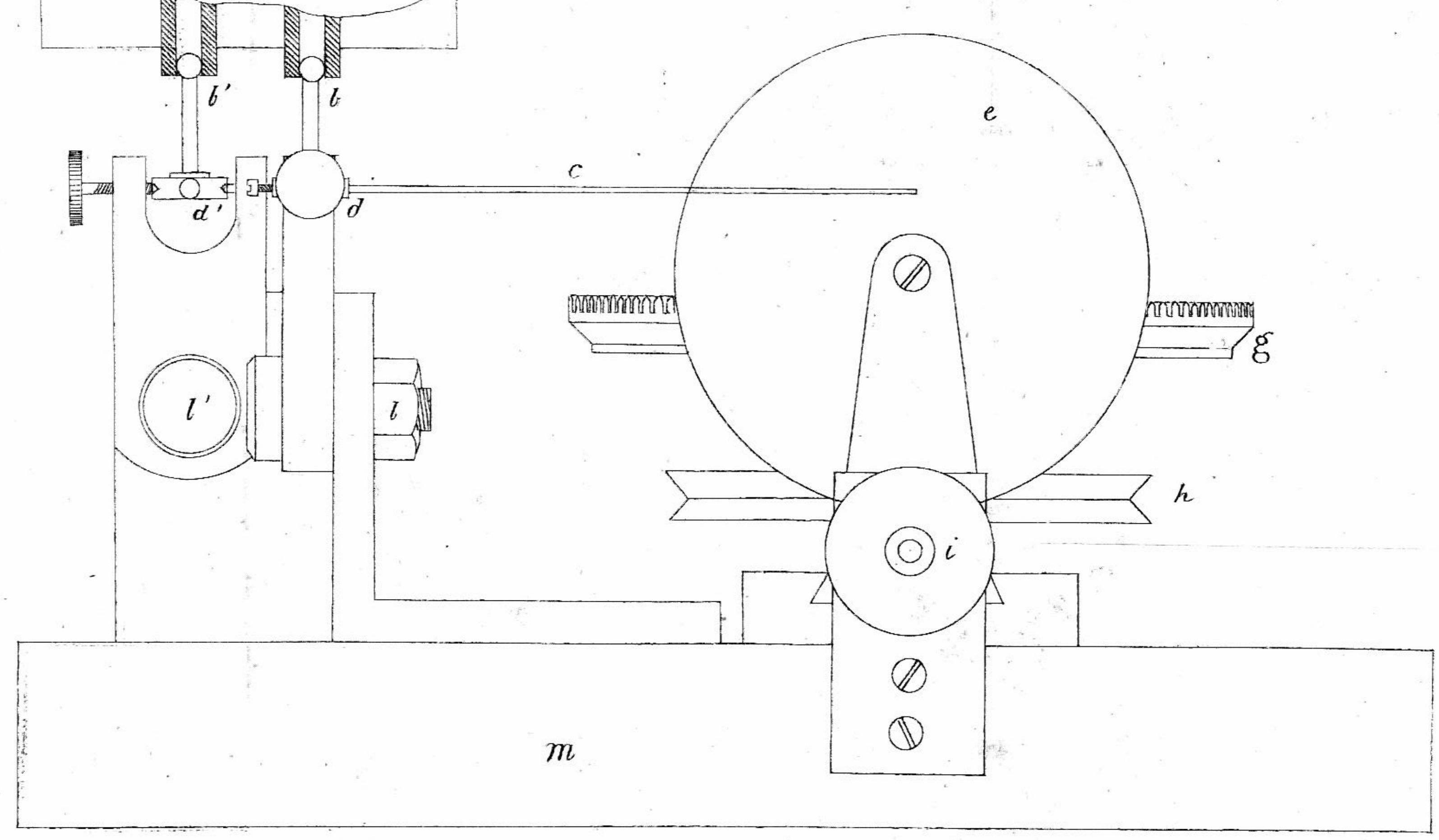


Fig 4. Full size.

periods measured as accurately as if the pendulum had remained at rest.

The bob of the pendulum is of the form shown in figures 1 and 2. It is a cast iron ring $16\frac{1}{2}$ inches in internal diameter, $20\frac{1}{2}$ inches in external diameter and 2 inches deep. It is crossed at one diameter by an iron bar at the middle of which, and close to the centre of gravity of the ring, the indicating levers are applied. The connection with them is made by means of two brass tubes a a' screwed into the iron bar, and into which fit very accurately without sensible friction or clearance the two spherical heads of the levers. These are seen in Fig. 3 and 4 (which give views of the recording apparatus) and are lettered b b'.

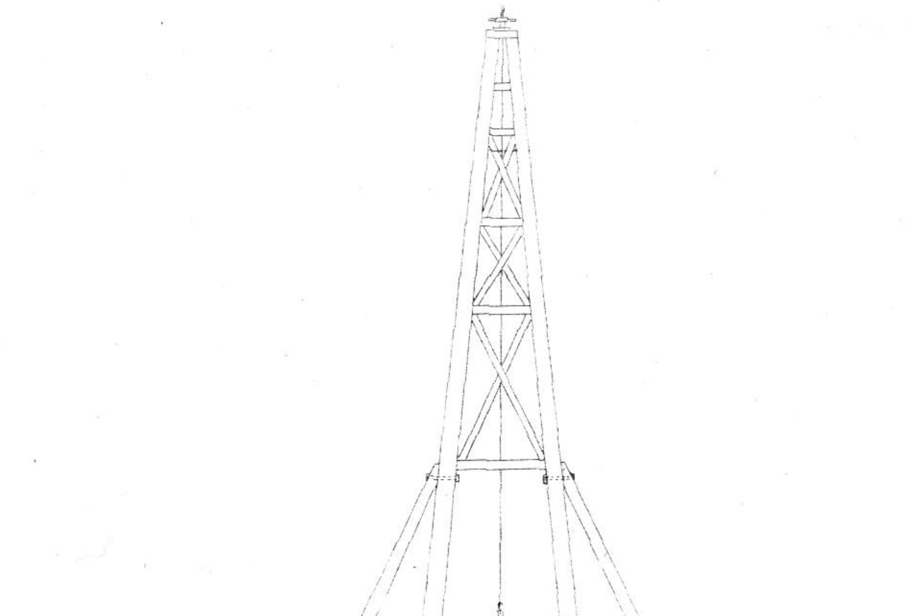
Each lever consists of a short upright piece, at the top of which is the spherical end fitting into the tube, and a long horizontal pointer (c c') made by beating out a brass wire flat, so as to be very rigid to resist bending in the direction in which the lever moves, but very flexible at right angles to that direction. The two parts b and c are connected to each other, and attached to the fixed support, by means of a gimbal joint d d'. The effect of this joint is that if one of the levers (say b) is moved in the plane through it and its pointer (c) it will carry the pointer with it, as if the two were rigidly connected; whereas, if b is moved at right angles to that plane, the pointer c will remain at rest, the short arm b revolving about the inner joint of the gimbals. Hence each pointer is affected only by motion in its own direction or opposite to that, but remains wholly unaffected by motion transverse to itself. Each, therefore, registers one of the components of the horizontal motion resolved along c and c' as axes. Fig. 3 gives a complete plan of the recording apparatus. From it and from Fig. 4 the construction of the gimbal joints will be apparent as well as the mode of their attachment to the fixed base of the instrument. The pointers c c' are five times as long as the upright parts b b' of the levers, and the motion of the earth is therefore magnified in record in this ratio.

The points of the levers c c' press very lightly against smoked glass plates e e', which adhere to brass bosses on the axles $f f'$. These axles carry two small pinions gearing into the teeth of the horizontal wheel g which is made to revolve uniformly and continuously by clockwork, to which it is connected by a band working in the *V* pulley h.

Figs. 4 and 5 are both only partial views of the instrument, certain parts having been omitted in each case for the sake of clearness. Fig. 4 shows the arrangement of the indicating levers with their gimbal joint supports, and the tubes a a' above them. Fig. 5 shows the contrivance used to carry and drive the glass plates e e', against which the points of the indicators press, but the levers themselves are there left out.

The axles $f f'$ which carry the glass plates are supported on brass frames capable of sliding in the direction of the length of these axles, and which can be moved backwards and forwards by the thumb-screws i i', by means of screws working in the nuts j j' fixed to the frames which carry the axles $f f'$. These frames are supported like the slide rest of a lathe, so as to have no freedom of motion except that just mentioned. The object of providing a means of which the axles $f f'$ can be drawn out or in is that the plates can thereby be removed from or brought into contact with the pointers at will. Thus when the instrument is first set up the plates may be kept out of contact with the pointers until the disturbed pendulum has had time to come to rest; also after the record of an earthquake has been obtained they may be put out of contact and then withdrawn without difficulty by unscrewing k k' and taking the axles $f f'$ bodily out of their bearings. The pinions on these axles are of such length that they will remain in gear with the wheel g throughout a considerable range of positions of $f f'$. The plates can thus be advanced or withdrawn, so as to press with any required force against the recording levers. Adjustments are provided by means of the bolts and nuts l l', by which the axles of the levers may be set exactly perpendicular to the planes of the plates, and the height of the levers be varied at will.

The recording apparatus stands on the top of a timber post 12 inches square (see Fig. 1) firmly driven into the ground and cut off short a few inches above the surface. The


level of
ground
Scale of
feet

author believes that a seismometer fixed on a post such as this will follow the motion of a point on the earth's surface much more exactly than if it were supported on one of the stone or brick tables commonly in use. The recording apparatus is held in position by three screws working in nuts fixed to the post, and pressing against three sides of the block *m*. One of these appears in Fig 2. This permits an easy adjustment of the horizontal position of the block, so as to get the levers *b b'* exactly under the holes in *a a'* before the pendulum is lowered down. The cast iron ring which forms the bob of the pendulum is supported by three wires fastened to rings *n n n* (Fig. 1) which converge to a single wire, and the single wire is fixed at the top of the supporting framework to an iron rod which can be raised or lowered by a screw. At the point of convergence of the three supporting wires a right and left handed screw joint is placed (*o*, Fig. 2), to admit of a further adjustment of length in the pendulum, and also to allow the bob to be turned in azimuth.

It should be observed that any small rotation of the bob in azimuth, after it has been set up, will produce no movement of the pointers on the plates, as the motions of *b* and *b'* will both be perpendicular to the planes formed by themselves and their respective indicating pointers, and the effect of the gimbal joints is that this kind of displacement produces no record.

Fig. 6 gives a general view of the instrument, showing the framing from which the pendulum is suspended and the foundations on which the framing stands. The drawing will make apparent what attempt has been made to secure the rigidity which is essential to the success of the instrument. The building in which it stands acts merely as a cover and does not touch the frame or its foundations.

The author has to express his indebtedness to the director and vice-director of the university for the facilities they have generously granted for the construction of the instrument now described.