ON STEADY POINTS FOR EARTHQUAKE MEASUREMENTS.

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In the present paper I propose to give a brief account of some attempts I have made to find a steady point from which to register the maximum amplitude and the direction of movement in an earthquake shock. The utility of an instrument which gives these elements has been several times questioned in this society, but still it appears to me very desirable to get these elements, where it is not practicable to get more. In the first place, a comparison of the amplitudes at different places, for any one shock, gives the relative intensity of that shock at these places, and in the second place the direction of shock at different places may lead to the discovery of the focus, and cause of the shock, and also to the effect of topography on its propagation.

I

On the Indications of a Vertical Pendulum Machine.

I communicated to this society some time ago a description of a seismometer which I had devised for the above purpose. In this instrument three horizontal components of the movement were sought to be measured by turning three small pulleys with pointers attached by means of threads fastened to the centre of inertia of a heavy mass which formed the bob of a vertical pendulum.

This instrument, like all of its class, was subject to error from the swinging of the pendulum caused by the shaking of the point of suspension and the friction and inertia of the pulleys and pointers. Besides this error I found the instrument somewhat troublesome on account of the threads changing their length with changes in the hygrometric state of the atmosphere, and also on account of the pointers tending to carry the pulleys too far round in virtue of the rotational energy imparted to them by the shock. The errors due to the last named causes have led to some slight modifications in the instruments to which I beg leave to call attention. For the threads I found it necessary to substitute fine wire, with a short length of thread at one end for the purpose of winding round the pulley, this alteration has however the effect of making the shock given to the pulley more sudden and consequently of rendering the error due to whirling more marked. This error however can be got over almost completely by either of the following methods. First, instead of fixing the index to the pulley, as was done in the machine described, let it be hung from the pulley by two fine threads forming a bifilar suspension. This allows the pulley to turn round leaving the index behind, it in its turn swinging slowly round and after a few oscillations taking up its new position. In this arrangement the inertia of the index tends to prevent rather than to increase the motion of the pulley, thus rendering the instrument much more accurate. Second, leave the pulley, with the index fixed to it, almost free to turn without friction, and pass the thread once round it and then under a weak spring. The friction of the thread beneath this spring may be made to hold the pulley in any required position, and also to prevent the pulley whirling when the thread receives a sudden pull. The instrument is somewhat simplified by leaving out the pulley altogether and simply using the index suspended by two threads, one of them hung from a point fixed to the earth, and the other from a light bar of wood, or wire, made to lie horizontally with one end against the bob of the pendulum. If the normal position of the plain of the threads be at right angles to this rod, the index will be turned through an angle, the tangent of which is proportional to the displacement of a point on the earth surface. The disadvantage of this arrangement is unequal sensibility for shocks of different magnitudes.

With regard to the errors which are common to all these instruments due to the swinging of the pendulum, I may remark that these are made very much smaller by diminishing the inertia of the recording parts; hence in my instruments they are extremely small when the bifilar arrangement is used. I have adopted, for the purpose of still further diminishing this error, a frictional resistance to the motion of the pendulum bob. This frictional resistance is produced by means of a vertical iron wire about 8 centimetres long, loaded at the top with about 50 grammes of lead, and made to slide freely through holes in two horizontal brass pieces, fixed, one to the top, and the other to the bottom surface of the bob. Using a bifilar suspension without pulleys, and this arrangement for controlling the swing of the pendulum, I obtained the following experimental results for amplitude and direction

TABLE I

Measured Amplitude in millimetres	0.3	0.5	1.5	0.5	1.5	2.1	2.5	0.25	0.35	0.35	0.5	0.3
indicated ,,	0.33	0.5	1.4	0.5	1.3	2.0	2.7	0.25	0.33	0.42	0.5	0.3

TABLE II

Measured direction....	7°	27°	40°	59°	66°	66°	18°	18°
Indicated ,, ...	7°.7	24°.3	41°.2	57°	65°.5	64°	17°	19°

In these experiments the machine was placed on a somewhat rigid table which was shaken backwards and forwards by hand in an irregular manner for about half a minute, and then the record taken. The measured amplitude was given by pushing a scale against the side of a fixed table, and the indicated amplitude was given by the machine. In the case of direction, the table was shaken as accurately as possible in the direction across its length. The angles given are the angles which the direction of one of the components of motion, as given by the machine, made with the direction of motion as supposed to be given to the table. The results do not pretend to minute accuracy, but they are sufficient to show that the indications of such a machine are probably not far from the truth.

It has usually been the practice to suspend the pendulum of an earthquake machine from a very rigid frame in such a way that the point of suspension was forced to move along with the earth. This was done under the impression, that, if the frame were not rigid, the top would probably swing through a greater distance than the earth's motion.

Probably if the pendulum were simply suspended from a loose frame this would be found to be the case. I think some advantage might be got by arranging a rigid frame in such a way that, if a point at the bottom be made to move quickly backwards and forwards, the top would remain steady. This might be accomplished by placing the frame on a spherical base and so proportioning the base and the frâme that the centre of oscillation would be near the top.

Perhaps the best form of neutral equilibrium machine will be found to be a conical pendulum with a very heavy ring, or pair of masses a short distance apart, for a bob. This bob may be hung from a point near its centre of inertia, while a stiff horizontal wire, (with one end pointed and resting at a point directly under the point of suspension, and the other end attached to the centre of the weight in such a manner that the weight is free to turn round a vertical axis through its point of attachment to the suspending wire,) may suffice to hold it in a position of approximatly neutral equilibrium. The registering lever may be a prolongation of this horizontal wire, or a separate lever made to turn round an axis at the centre of the ring with a point very near the axis rigidly fixed to the earth. With this arrangement a very large multiplication may be obtained. I hope at a future time to communicate results of a trial of an instrument of this form to the society.

II

Horizontal Pendulum Machines.

About a year ago I began to make experiments on horizontal arms pivoted at one end and carrying a heavy weight on the other. The pivoted arms which I used where about 30 centimetres long and carried about 5 kilogrammes on the free end. This mass seemed to remain pretty steady even when an oscillatory motion of two or three centimetres was given to the pivoted end if that motion was at right angles to the length of the arm. If however the motion was inclined to this direction the arm tended to turn round and remain in a new position. This displacement of the arm of course rendered the instrument, in this form, practically useless for my purpose. I have since modified my horizontal arm arrangement to the form shown in Fig 1. It is to this machine I wish to call special attention. This instrument consists of a double or jointed arm L, pivoted at one end in a rigid frame *f*, and supporting at the other a heavy lead ring R. The heavy ring is free to rotate round a vertical axis through its centre, and at the same time to revolve round other two vertical axes, one at the joint, the other at the pivot. When the instrument is in use the two halves of the arm are at right angles to each other, and hence the heavy ring may remain absolutely stationary no matter in what horisontal direction the pivot is moved. The levelling screws on the frame *f*, allow the arm to be so adjusted that the ring is in the position of minimum potential energy when the two halves are at right angles. The stability in this position can also be adjusted by these screws and should just be sufficient to preserve this arrangement. If now the two halves of the arm be so adjusted that the line joining the pivots, and the axis of the joint stand in the relation of axis of percussion and of spontaneous rotation* for the first half, and again, the

* *I believe the first time special attention was paid to the application of this well known dynamical principal to Seismometers is to be found in a paper communicated by Prof. Ewing to the last meeting of this society. In the present instrument the arms are so very light in comparison with the ring that I did not consider it necessary to enter into particular calculations on the subject.*

axis of the joint and the axis of the ring in the same relation for the second half, there will be no tendency, except that due to friction, for the ring to move when the frame *f* is moved horizontally. This ring then, may be made to serve as a steady mass which by its inertia is capable of moving a system of light levers for registering purposes. If the two halves of the arm be ~~made short, as shown in~~ the drawing, then two light levers forming a continuation of their length would be sufficient to give, on a magnified scale, two components of the motion. I prefer however to take off the motion directly by means of a vertical lever I, working in universal joints at J. J. These joints are formed by an ordinary brass toilet pin passed through holes in very thin plates. The index, which is made of light wood or straw tipped at the end with a needle point, hangs when free by the head of the pin. This index need not be specially light if it be so proportioned that, when the joint which is fixed to the earth is moved, it tends to turn round the joint which is fixed to the weight. The needle at the end of the index is so arranged that it can slide up and down through holes in small aluminium plates fixed to the ends of a fine tube. This motion is required in order that the point may remain in contact with a flat plate during its backward and forward motion.

It will be noticed, that, according to the mode of registering which I propose to adopt, there is no necessity, except for compactness, for the horizontal arms being so short as they are shown in the drawing. The instrument would no doubt be more perfect if the arms were longer and consequently the angle turned round the different joints smaller.

It may be objected to in the mode of registering proposed here, that the ring will tend to turn if a moving plate be used for receiving the register, as in clockwork instruments. When we consider the amount of statical friction which must necessarily exist in these instruments, it is not at all likely that a fine needle rubbing a smooth glass, or varnished, surface will, even with a considerable leverage, have power to begin motion in the ring.

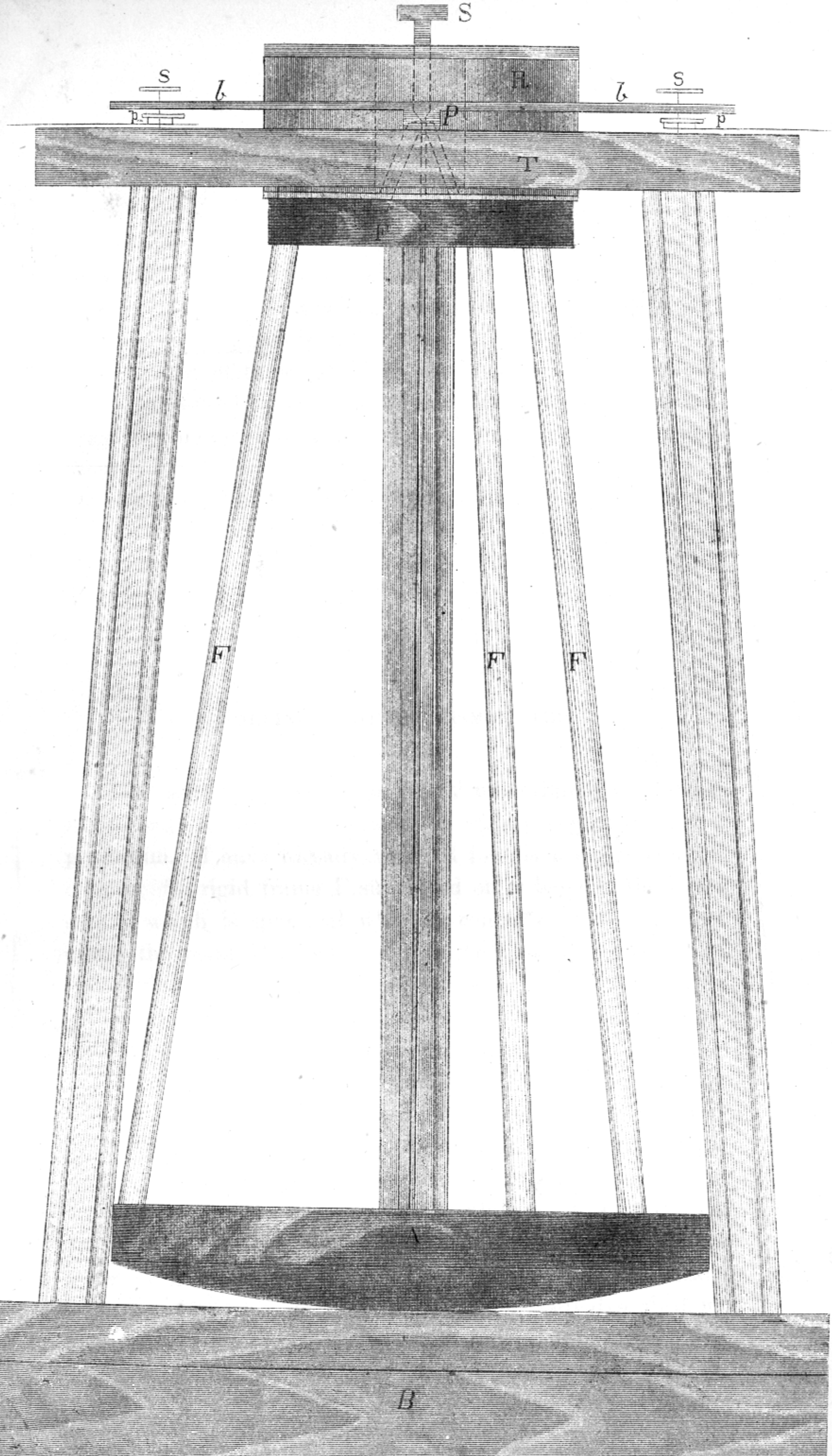

Fig 2

The distinctive feature of this machine is the jointed arm and the single mass. The jointed arm renders it possible for the mass to remain steady during a shock in any azimuth, thus removing one source of error, namely, the shock given to the axis when the motion is in the direction of the lever.

The first of these machines is in course of manufacture, and is to be used by Prof. Milne in connection with a continuously moving clockwork arrangement for registering the whole shock.

An important feature in this machine is, that when the motion is taken off directly in the way I have indicated, even on a stationary plate, the record ought to show whether the direction remained constant during the whole shock.

III

Rolling Sphere Seismometer.

The contrivance shown in Fig. 2 was originally intended to illustrate a mode of obtaining a steady suspension for a pendulum. I have already referred to this arrangement; it consists of a rigid frame F supported on a base A, the lower side of which is spherical with its centre of curvature just above the point P which supports the ring R. The size of base and of the frame is so proportioned, that the point P is stationary when the bottom is rolled backwards and forwards with a moderately quick oscillatory motion.

The instrument is better suited for earthquake registration without a pendulum, and in this form it is shown in the drawing. The drawing shows the instrument either arranged to give two components of the motion or the total motion directly. On the base B a frame carrying the platform T is fixed. A brass frame *b* with adjusting screws *s* for holding the pulleys *p p*, is fixed to the platform T. The pulleys *p p* carry by means of short threads, according to the method already described, indices of such length as to give a multiplication of forty. The arrangement for registering the total motion and direction directly, is precisely the same as I have just described for the horizontal pendulum machine and requires no further description.

This instrument is remarkably steady for long continued and large motions.

Plate III shews a much more compact form of this machine. The only difference is that the sphere is reduced to about two centimetres radius, and the registering index fixed rigidly to it, rises up above and registers on a plate of glass G by means of a small steel sewing needle which passes loosely through holes in two small pieces of aluminium foil fixed to a piece of cork L. The radius of the sphere forms the short arm of the registering lever in this case, while the whole is held steady by about 5 kilogramms of lead in the form of a ring R resting on a pivot P just under the centre of the sphere.

Both these machines are suited to show not only the amplitude on a large scale, but the direction both of the direct and transverse shock.

DISCUSSION.

Mr. Ewing said that Mr. Gray's valuable paper showed how great an advance there had been in the science of seismic measurement during the last year or two, or even, he might say, since the foundation of the society. He believed that any one of the devices which Mr. Gray had shown to the meeting, was better to an indefinitely great degree than any earthquake indicator in existence a couple of years ago, with the possible exception of Dr. Verbeck's arrangement of a massive slab supported by smooth spheres standing on a plane base. He still held most strongly the opinion, that no contrivance to obtain a so-called "steady point" could be relied on to give trustworthy results, unless it acted in conjunction with a time register, so that gradual changes in the position of the "steady point" could be distinguished from the earthquake records. Without this, the information given by all such seismometers was at the best so imperfect as to be scarcely useful, and so liable to indeterminate errors as to be untrustworthy. Any one of Mr. Gray's arrangements for a "steady point", if provided with recording indices to mark on a continuously moving surface, would probably make a really good seismograph. The members who had been present at the last general meeting of the society, when his (Mr. Ewing's) Astatic Horizontal Lever Seismograph was exhibited, would recognise that each of Mr. Gray's contrivances was an application of the method used in that instrument, *the method namely of supporting a mass by a movable piece in such a manner that the connection with the earth was at the centre of percussion of the movable piece, the mass being at the corresponding centre of instantaneous rotation,* while at the same time the supporting piece was arranged so that its movement did not introduce any disturbing force due to the action of gravity upon the mass. This kinetic property common to all these instruments, he believed he might fairly claim to have introduced into seismometry. The one of Mr. Gray's forms of apparatus which most closely resembled his seismograph in appearance, was the "double bracket" arrangement described in the paper. Compared with his (the speaker's) instrument, that arrangement differed in having only one bob or heavy mass instead of two masses independently supported. The simplification was, however, apparent rather than real, for the double-jointed arm would present considerable difficulties in construction and adjustment, so as to get the three axes parallel. Mr. Ewing believed that the complication of levers, necessitated by the use of only one bob, made the change on the whole a disadvantage, and that his own seismograph in its original form, was in reality easier to make and use, and was to be preferred except where, for special purposes, two degrees of freedom were desired.

Mr. Gray said that Mr. Ewing had called attention to an application in all these machines of a principle which he claimed to have introduced into seismology.

He believed that Mr. Ewing was the first to introduce this principle explicitly, perhaps the first to recognise its existence. The condition implied by this principle was approximately fulfilled in all the machines, but was not introduced quite in the way Mr. Ewing seems to suppose. In his case the application of this principle was made an important feature; in this case it received no further notice than was implied in making the lever so light that its effect might be neglected. When the lightness of the framework and comparatively great friction error which must it almost all cases exist in these machines was considered, it seemed almost superfluous to make refined calculations on the subject. In the rolling sphere machine this principle enters and is capable of more accurate application, the instantaneous axis in this case being always at a point in a vertical line through the centre of gravity and at constant height above it. In all his experiments on this apparatus, he had used a weight rigidly fixed, and determined the steady point experimentally. It had not occurred to him to attack the problem in the way proposed by Mr. Ewing, and now that this was before him he saw considerable difficulty in improving on his old method. The principle of neutral equilibrium used in all these instruments has of course been in use for a long time.

Mr. Ewing referred to the double lever arrangement as an apparent simplification of his horizontal lever arrangement. The machine lays no particular claim to simplicity, although Mr. Ewing seems to imagine it more complicated than it really is, and seems to place but little confidence in the skill of the manufacturer. The distinctive feature of the machine, was stated to be its having only one heavy mass so pivoted that it could remain steady no matter in what azimuth the point of support moved. This Mr. Gray considered of great importance as it took away one very decided cause of disturbance to which single lever machines are subject. He also considered this of great importance in connection with the determination of the existence of both a direct and transverse wave in an earthquake. A record from such a machine whether on a moving or a stationary plate (preferably the latter), would give easily detected evidence of such waves. Owing to the machine having been described from a diagram instead of from the written paper, the part referring to the arrangement for two components had been inadvertently missed out. In that part reasons are given why a complexity of levers need not be used. The method suggested by Mr. Ewing might however be found valuable if necessary.

With regard to the difficulty of construction he did not anticipate that it would be found greater in this machine than in one of Mr. Ewing's single lever arrangements.