13. *On the Problem of Instabilities of Higher Orders in a Seismometer. III. Experiments with a New Vertical Vibration Table.*

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1. *Introduction.*

In the previous paper,[1] the main point ascertained was the effect of vibration damping on the stability of a seismometer. In the same paper, the order of instability, particularly in experiments, was for such part as is near 1/2. In the present paper, the range of the instability condition has been extended to that of 3/2 as well as 4/2. Since our new vibration table of vertical type was only recently constructed, the instabilities under consideration were investigated by means of this table as well as by the horizontal vibration table in use since last year.

2. *A new vertical vibration table.*

Our new vertical vibration table is of the type shown in Fig. 1. The table T, 130 cm long and 40 cm wide, rotated about the axis AA. As the longer arm of the table was 100 cm long, if a seismometer or a structure model were placed near the end of the longer arm in question, it would be possible for the motion of that part to be virtually undergoing an up and down motion so long as the amplitude of that part exceeds a few milimeters. However, the amplitude during the experiments was always less than a milimeter. A steel plate weighing 50 kg was hung on the shorter arm, 30 cm long, in order to balance the static moment arising from the longer arm. The steel axle AA, 12 mm in dia. was mounted on ball bearings. The remaining part of the table, including the foundation of the ball bearings, was of cast aluminium and of framed construction. Wooden boards were placed on the top of the table.

The table was moved by a motor M of Leonald type through a steel

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[1] K. KANAI and K. SEZAWA, "On the Problem of Instabilities of Higher Orders in a Seismometer. II," *Bull. Earthq. Res. Inst.*, 19 (1941), 9~13.

rod R of 19 mm dia., aluminium frame F, and steel springs S_1, S_2. The axle BB, a steel rod, 19 mm in dia., was also mounted on ball bearings. The crank pin end and the other end C of the rod R were both ball bearing.

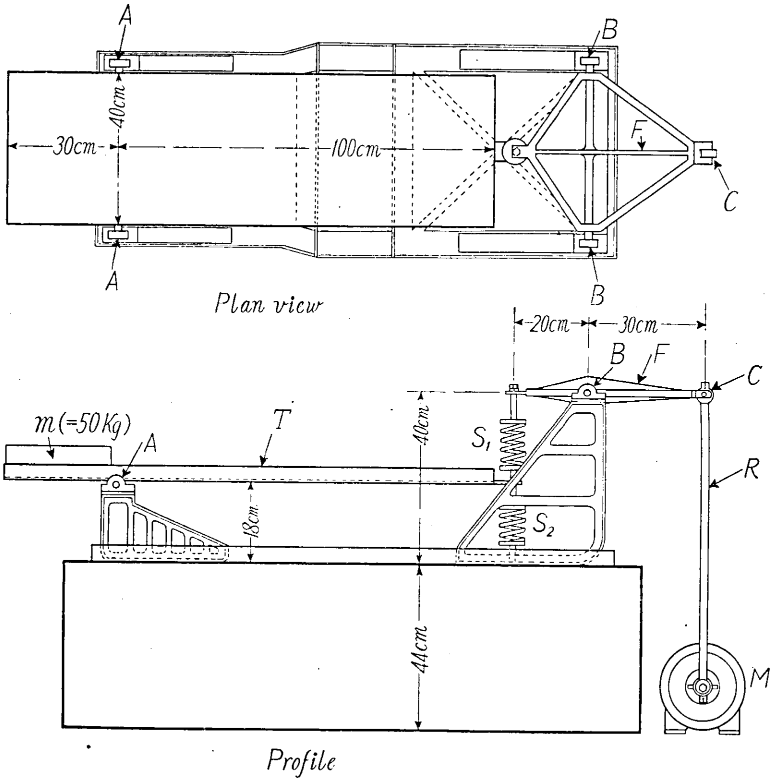

Fig. 1.

Owing to the presence of springs S_1, S_2, the table vibration was in resonance condition at a frequency of 1,200 per min. The range of cycles during the experiments was thus from below 1,200 per min. to 100 per min.

The motor driving system and the frequency measuring instrument were the same as those shown for the horizontal vibration table.[2] Since the vibratory motion of the table was about the pivot axis AA, oscillation in the present case was more satisfactory than in the case of the horizontal vibration table. Notwithstanding springs S_1, S_2, the vibration

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[2] K. KANAI and K. SEZAWA, "Effect of...and Model Experimental Confirmations of that Effect with a New Vibration Table," *Bull. Earthq. Res. Inst.*, **18** (1940), 370~383.

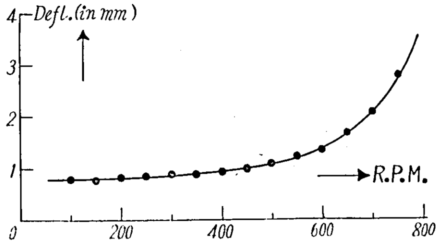

Fig. 2.

amplitude was always about 0·85 mm for such a wide range as that between 100 per min. and 400 per min. The amplitudes of the table observed for vibrational frequency between 100 per min. and 800 per min. are shown in Fig. 2, from which it will be seen that for frequencies less than 400 per min. the amplitudes were almost constant.

3. *Experiments with the vertical vibration table.*

Using the vertical vibration table shown in the previous section, the vertical stability of a horizontal seismometer was ascertained experimentally. The equivalent pendulum length, the natural period, and the mass of the seismometer used in this case were $L=11$ cm, $T=0{\cdot}133$ sec, $M=15$ kg, respectively. Because the pendulum was movable horizontally and at right angles to the direction of the pivot axis of the table, asymmetry of the pendulum motion resulting from small inclinations of the table was avoided. The movements of the pendulum were recorded optically, through a small mirror attached to the pendulum, on a bromide paper on a drum that lay at a certain height above the pendulum.

The vibration damping of the seismometer involved seven cases, the logarithmic decrements of which were $\kappa=0{\cdot}13$, $0{\cdot}23$, $0{\cdot}33$, $0{\cdot}90$, $1{\cdot}5$, 2, $2{\cdot}7$, in sec^{-1} unit. Since the value of κ for critical damping in the present condition of the pendulum was $\kappa=47\ \text{sec}^{-1}$, the damping used in the experiments were much smaller than that in an actual seismometer. From the optical records for different vibrational frequencies of the table in these various cases, the actual displacements of the centre of percussion of the seismometer were calculated, with results as shown in Figs. 3∼9.

Since the natural period of the pendulum was 0·133 sec, frequencies of the 2/2, 3/2, and 4/2 orders of instability should have occurred at 451 per min., 300 per min., and 226 per min., respectively. From the experiments, it will be seen that the large amplitudes of the pendulum occurred close to such frequencies although there were some deviations. These deviations were the effects of vibration damping. It should be borne in mind that since resonance condition also participated in the 2/2 order of instability, amplitudes of the same order were not shown in the results.

A special feature of all the experiments was that although the vibrational frequencies of the table were changed for a wide range, the seismometer oscillated always with its natural frequency. This is the

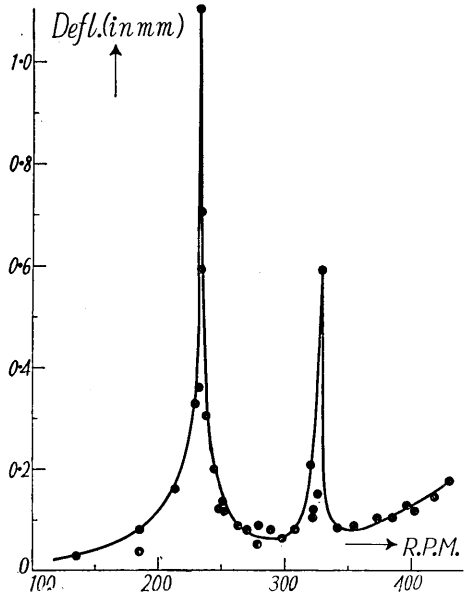

Fig. 3. Deflection of the centre of percussion in the case of $\kappa=0{\cdot}13$.

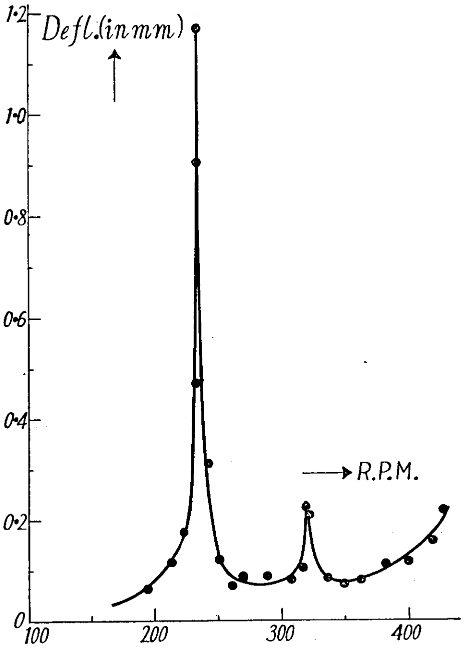

Fig. 4. Deflection of the centre of percussion in the case of $\kappa=0{\cdot}23$.

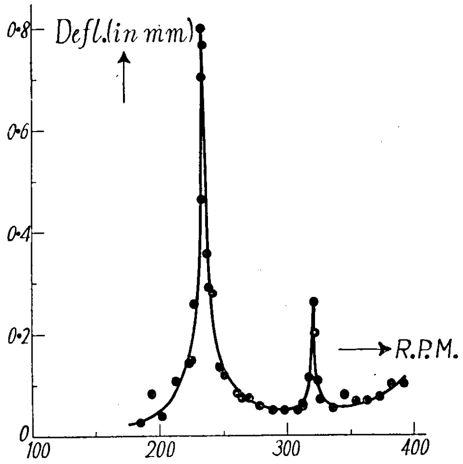

Fig. 5. Deflection of the centre of percussion in the case of $\kappa=0{\cdot}33$.

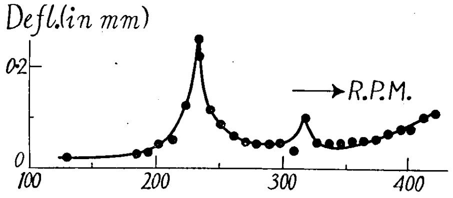

Fig. 6. Deflection of the centre of dercussion in the case of $\kappa=0{\cdot}90$.

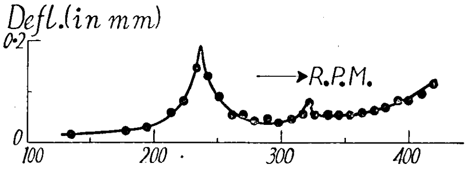

Fig. 7. Deflection of the centre of percussion in the case of $\kappa=1{\cdot}5$.

reason why the results in Figs. 3∼9 represent instability, and are not resonance curves. However, the instability shown in the present experiments was not vibrational instability in the usual sense, not the vibration that augments without limit with time increase. As already mentioned in the previous paper, the seismometer becomes abnormally sensitive for certain frequencies of the table vibration, from which it is also assumed that some small amplitude at a frequency intermediate between those of the instability conditions in the present experiments, arose as the result of increase in the sensitivity of the seismometer with certain motions of the table.

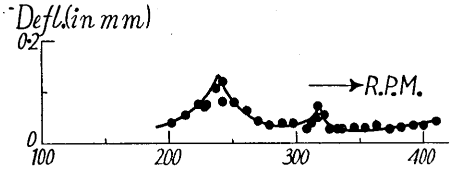

Fig. 8. Deflection of the centre of percussion in the case of $\kappa=2{\cdot}0$.

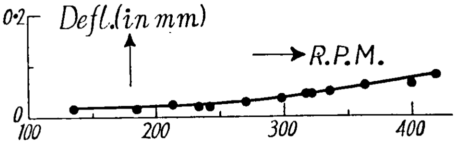

Fig. 9. Deflection of the centre of percussion in the case of $\kappa=2{\cdot}7$.

Comparing Figs. 3∼9, it will be seen that the amplitudes of instability conditions diminished enormously with increase in the vibration damping of the pendulum. Even for such a value as $\kappa=2{\cdot}7$, there is no peak in the curve of the vibration amplitudes (see Fig. 9), whence it holds that for critical damping of the seismometer, that is to say, $\kappa=47\,\mathrm{sec}^{-1}$ in the present case, it is not possible to consider any instability effect, at any rate, for the 4/2 and 3/2 orders of instability. For confirming the effect of change in κ on the instability condition, the amplitudes at the frequency for the 4/2 order of instability for different values of κ were replotted in Fig. 10. The curve becomes nearly asymptotic to the abscissa at $\kappa=2{\cdot}7\,\mathrm{sec}^{-1}$, that is, the abscissa much less than that corresponding to critical damping ($\kappa=47\mathrm{sec}^{-1}$).

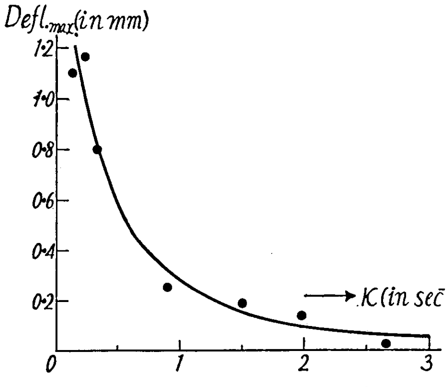

Fig. 10. Maximum deflection of the centre of percussion for different κ's.

4. *Experiments with the horizontal vibration table.*

The main purpose of the present paper is to show the instability condition of a horizontal seismometer for vertical vibration of the ground. Since however the problem was restricted to the 4/2 order and 3/2 order of instabilities (these instabilities had not yet been studied), the instabilities of these orders were also ascertained with the horizontal vibration table.

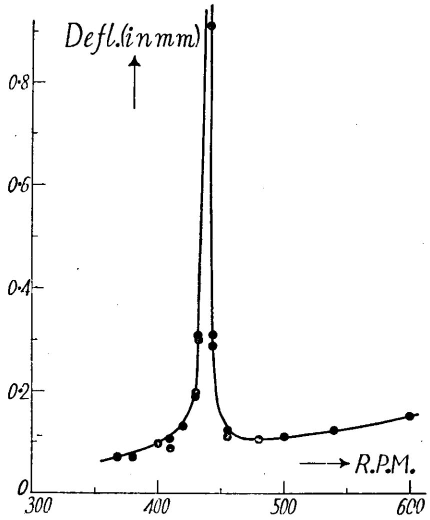

Fig. 11. Deflection of the centre of percussion in the case of $\kappa=0{\cdot}085$.

The table used in the present experiment was the same as that shown in the previous paper. The seismometer was so placed on the table that it could be moved horizontally about a vertical axis and at right angles to the direction of the oscillation of the table. Thus the axis of rotation of the pendulum in the present case differed 90 degree from that in the case of the vertical vibration table.

The natural period and the mass of the seismometric pendulum also differed from those in the previous case, but the equivalent pendulum length was the same as that for the vertical vibration table. The values under consideration were $L=11$ cm, $T_0=0{\cdot}0681$ sec, $M=1$ kg., respectively. Since there were no springs used in the horizontal vibration table, the amplitude of the same table was kept always at 2 mm for any

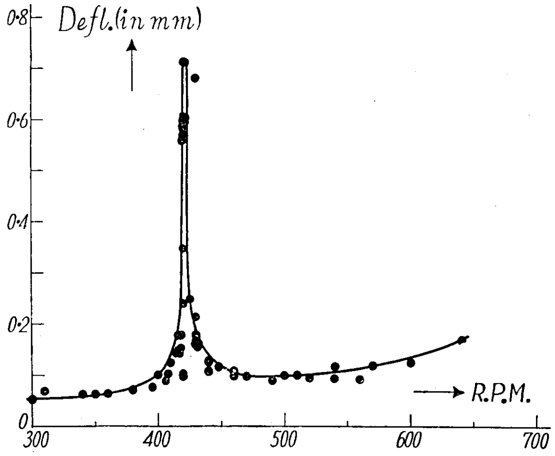

Fig. 12. Deflection of the centre of percussion in the case of $\kappa=0{\cdot}36$.

frequency. The vibration damping was of five kinds, namely, $\kappa = 0{\cdot}085$, 0·36, 1·03, 2·95, and 5, in $\sec^{-1}$ units. In this case, too, the displacements of the centre of percussion were calculated from records observed optically, the results of which are shown in Figs. 11～15. Although there is no appreciable peak for the 3/2 order of instability in the present case, the peaks corresponding to the 4/2 order of instability (frequency =447 per min.) are very marked, particularly, for smaller values of κ. When, however, $\kappa = 5$, the amplitude for the peak in question is almost indiscernible. The amplitudes of the 4/2 order of instability were replotted in Fig. 16. The reason that the amplitude in Fig. 16 does not touch the abscissa even at $\kappa = 5\,\sec^{-1}$, is rather that the general amplitude of the pendulum does not vanish for a large value of damping.

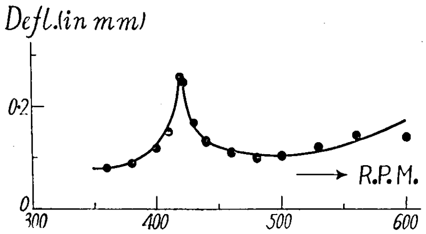

Fig. 13. Deflection of the centre of percussion in the case of $\kappa = 1{\cdot}03$.

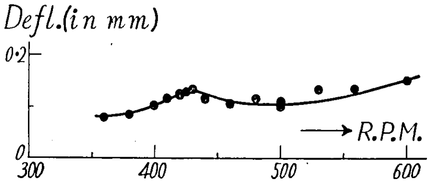

Fig. 14. Deflection of the centre of percussion in the case of $\kappa = 2{\cdot}95$.

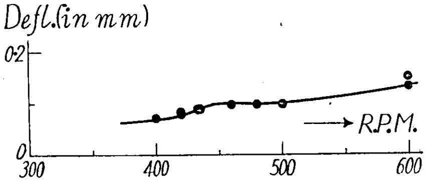

Fig. 15. Deflection of the centre of percussion in the case of $\kappa = 5{\cdot}0$.

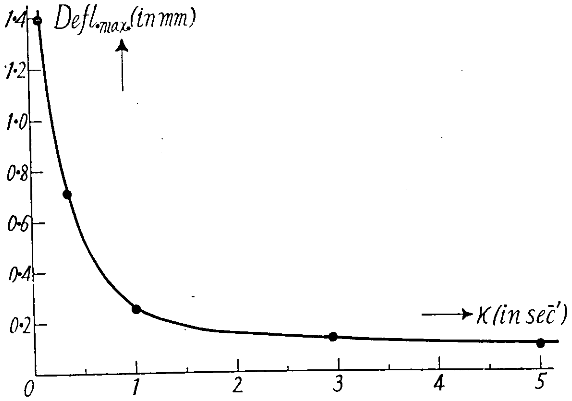

Fig. 16. Maximum deflection of the centre of percussion for different κ's.

The important feature of the vibration in the present case is that, as in the vertical vibration table, the seismometric pendulum oscillated with its natural frequency for any frequency of table vibration, whence it follows that the nature of the instability for horizontal vibration was the same as that for vertical vibration.

5. *Concluding remarks.*

The instability conditions of the 4/2 and 3/2 orders in a horizontal seismometer were ascertained with the new vertical vibration table as well as with the horizontal vibration table shown previously. It was found that although the instabilities in question were not vibrational instabilities in the usual sense, that is, vibration that augments without limit with time increase, their features are such that the sensitivity of the seismometer becomes abnormally large for certain frequencies of ground movements at right angles to the movable direction of the same seismometer. The seismometric pendulum in such ground motion, should oscillate with its natural period for any frequency of the ground movement, including the frequencies that correspond to the instability condition of the pendulum.

In conclusion, we wish to express our thanks to Mr. Kodaira, who assisted us greatly in our experiments. We also wish to express our thanks to the officials of the Division of Scientific Research, in the Ministry of Education, for financial aid (Funds for Scientific Research) granted us for a series of investigations, of which this study is a part.

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13. 地震計に於ける高次の不安定に就いて (第3報)
新しい上下動振動臺による實驗

地震研究所 金井清
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水平動地震計の 4/2 次及 3/2 次の不安定を新しい上下動振動臺及びこの前からの水平動振動臺を用ひて確めた．このやうな不安定は普通の意味に於ける不安定即ち振幅が時間と共に際限なく増加する不安定ではないけれども，地震計の動く方向に直角をなす地動が特定の周期になるときに地震計の感度が異常によくなるやうな意味での不安定である．このやうな周期に於て地震計が振動する周期は地動のそれではなく，地震計の自己周期に當つてをる事もわかつたのである．