19. *Phase Lag of Vibrations of Buildings Excited by a Vibrator.*

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Dominant periods of building vibrations have been measured with their vibrations caused by wind gusts or by earthquakes. Recently ground vibrators have been used to excite building vibrations. The writer attained the dominant period from the phase lag of building behind the vibrator.

The ground vibrator used by the writer was reported in this journal.[1] The wheels of the vibrator were rotated by a man as fast as possible, and then allowed to rotate freely, so the forced vibration of the building was gradually prolonged, and its amplitude decreased as the rotation of the wheels grew slow. But when the dominant vibrations resonate with the rotation of the vibrator, the amplitude of building vibration becomes maximum.

We recorded vibrations of several apartment buildings in Tokyo. Instruments for the observation were vertical vibrographs of mechano-optical magnification designed by the writer. The condition of the instruments was $T=3.0$ sec., critical damping and $V=850$. Once in one

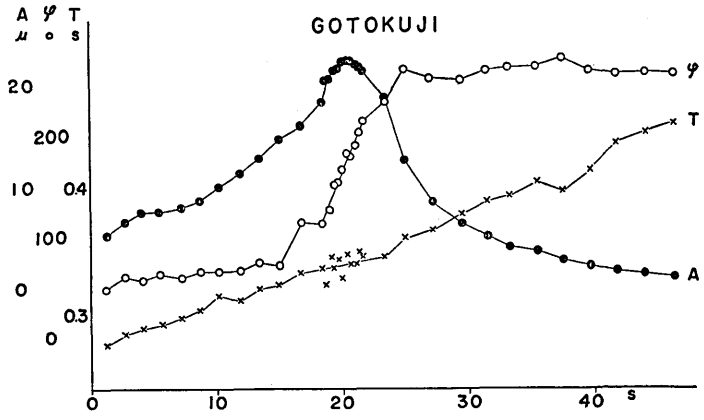

Fig. 1.

1) F. KISHINOUYE, *Bull. Earthq. Res. Inst.*, **33** (1955), 495–497.

revolution of the vibrator wheel, an electric contact was closed, and image of vibration made was interrupted by a shutter. The breaks of image showed the phase difference of the vibrator and building vibration.

Several examples of the measurement were carried out at apartment houses of similar size and shape. Three examples, observed at Gōtokuji, Kyōdō and Senjyu, are shown in Figs. 1, 2 and 3. In the graphs, A denotes the double amplitude in μ, T the period of building vibration caused by the vibrator, in sec, φ the phase difference in degree from arbitrary commencement, and the abscissa expresses time of observation which was also begun arbitrarily.

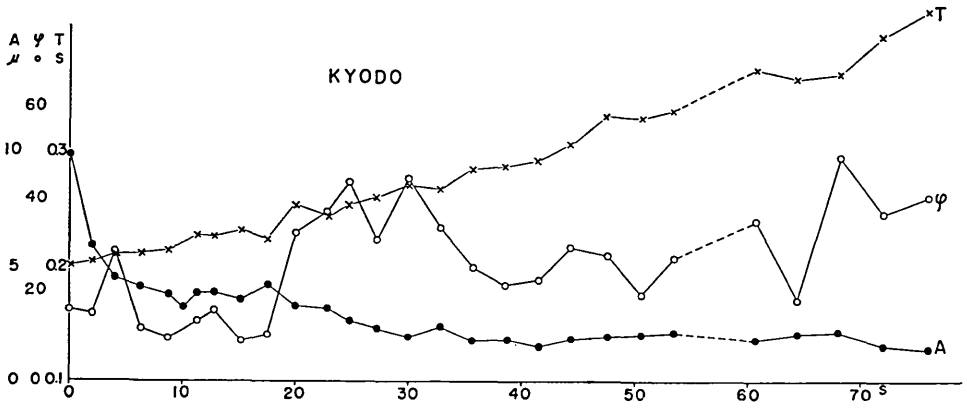

Fig. 2.

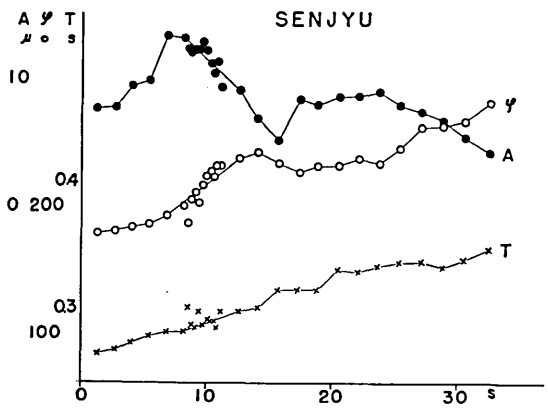

Fig. 3.

To explain the results, we assume that the building vibrates as a pendulum which has a damper. The vibrations we observe are regarded as vibrations forced by a simple harmonic motion of the vibrator. The above assumption can be expressed mathematically

$$\frac{d^2x}{dt^2}+2\lambda\frac{dx}{dt}+n^2x=f\cos pt$$

in usual notations. The right-hand term expresses the action of the vibrator. The solution of the equation is wellknown

$$x=\frac{f\cos(pt-\varepsilon)}{\sqrt{(n^2-p^2)^2+4\lambda^2p^2}},$$

where $\varepsilon=\tan^{-1}\frac{2\lambda p}{n^2-p^2}$ and gives the phase lag, and it varies according to the relation below:

$$0<\varepsilon<\frac{\pi}{2} \qquad \text{for} \quad p<n,$$

$$\varepsilon=\frac{\pi}{4} \qquad \text{for} \quad p=n,$$

and

$$\frac{\pi}{2}<\varepsilon<\pi \qquad \text{for} \quad p>n.$$

This relation shows that the value of ε changes sharply as p changes near $p=n$, or resonance case.

The result obtained at Gōtokuji (Fig. 1) is a good example of the above consideration. The phase angle changed remarkably at the amplitude maximum. In the case of Kyōdō Apartment House two maximum amplitude and two corresponding phase changes are seen in Fig. 2. Similarly two dominant periods are shown in Fig. 3, although Dr. Kanai and others[2] found one more dominant period, or three dominant periods for this house. But the third period was out of the period range of our observations.

In conclusion we consider that the observation of phase lag of building vibration can be another measure of dominant period of building besides maximum of amplitude variations.

This experiment was carried out by the writer as a member of the Subsoil Research Team, Earthq. Res. Inst., and he expresses his thanks to his colleagues on the term for their cooperation in the observations. Also he expresses thanks to Miss M. Kotaka, and Mr. H. Takahashi for their help in observations and measurements.

2) K. KANAI and others, *Research Report (Ronbunshū) Archit. Inst. Japan*, No. 24, (1953), 185.

19. 起振機による建物の振動の位相差測定

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建物の固有振動周期を知るのに遠心力を利用した起振機を用いる場合，起振機の車輪を速く回転させて放すとその回転が次第に遅くなり建物の振動は小さくなるが，起振機の回転が建物の固有周期と共振する所では振幅の極大が現われることはよく知られている．共振の場合には振幅ばかりでなく振動の位相も大きく変わる筈であるので，筆者は起振機と建物の振動との位相差を測定し固有周期を見出した．実例として東京都内の豪徳寺，経堂，千住の3個の大きさ，構造共に殆ど等しく，地盤の違うアパート建築について行つた実験結果を示した．