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14. *An Instrument for Brief Measurement of the Natural Period of a Building.*

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1. Introduction

It is needless to say that the natural period of vibration of a building is one of the most important factors for determining the dynamic behavior of the building during an earthquake.

Three methods have been hitherto used for measuring the natural period of actual buildings. Among these the vibrator method (resonance method) using a vibrator to excite the building vibrations gives us a considerable accuracy of measurement, and is most generally used. The other two methods may be called the indicial and the random response methods. One is to analyse of the damped free vibration of building caused by the force of unit-step form generating, by pulling and letting it go and the other is to measure its minute vibration excited by irregular forces such as microtremors and others. Each method has its strong point, but one great advantage of the third method may be that it enables us to procure the natural period of buildings without any vibration generators or other special devices.

The principle as well as the construction of an instrument for measuring the natural period of a building, which the third method is applied, is our concern in these pages.

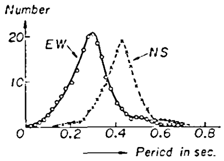
2. The predominant and mean periods of the vibration of buildings in normal times

Some of the period distribution curves obtained from the vibration records of buildings in normal times are shown in Fig. 1. The vibrograph used in the measurements is a microtremor recorder having a maximum magnification of about 10,000. In Fig. 1 a reinforced concrete and a steel framed reinforced concrete building, and a Japanese style wooden house are taken as examples of the different types of construction. The period distribution curves are the results of an analysis of vibration records for two minutes.

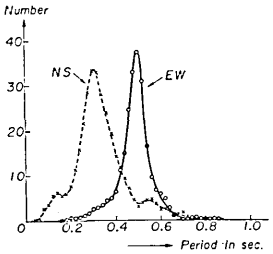
The period distribution curves, in many cases, are represented by a fairly simple shape having only one peak as seen in Fig. 1. This figure shows us that the predominant period of ordinary vibrations of a building can be ascertained easily with considerable accuracy from the period distribution curve.

The relation between the predominant periods of many buildings thus obtained and their resonance periods obtained by the vibrator method is shown in Fig. 2. The buildings treated here include various types of construction, that is, reinforced concrete, steel framed reinforced concrete, mortared frame wooden and wooden buildings in Japan and the United States. These buildings also differ greatly in dimension and in shape.

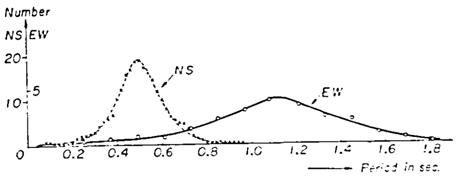
It may be said from Fig. 2 that the predominant and resonance periods agree well with each other. Hence we may obtain the natural period (the fundamental) of a building with comparative ease which is to take the vibration measurement of a building at a normal time instead of following the vibrator method. Nevertheless, the practical work of drawing up the period distribution curve from a vibration record is considerably



Hosaka (2 storied wooden house)



Chūō Kōron (6 storied SRC bldg.)



Hollywood Storage (10 storied SRC bldg.)

Fig. 1. Examples of the period distribution curves of the vibrations of actual buildings in normal times.

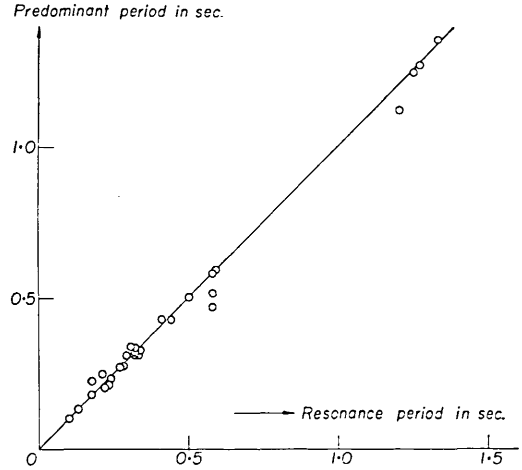


Fig. 2. Relation between the predominant period in normal times and the resonance period obtained from the vibration experiments of the actual buildings.

laborious.

On the other hand, since the period distribution curve has an almost symmetrical shape on both sides of the peak as seen in Fig. 1, it is to be expected that during a measuring time of the vibrations the mean period nearly coincides with the predominant period. In other words, the mean period of such vibrations of a building also should be coincident with the resonance period obtained by the vibrator method.

3. Natural period meter

With the above expectations in mind, we designed and constructed a new instrument which we have called the "Natural period meter" for measuring natural period of buildings.

The constitution of the period meter can be deduced readily from the block diagram illustrated in Fig. 3, which shows its essential parts. The natural period meter consists of a horizontal component transducer and a pulse counting unit including an amplifying circuit, and provides the mean values of period and frequency. The transducer is of a moving-coil type, and is provided with an inverted pendulum having a period of 1.0 second. The pulse counting unit is composed of a voltage amplifying circuit, a RC-integrating network, a low-pass filter, an amplitude limiter and two different electromechanical impulse registers.

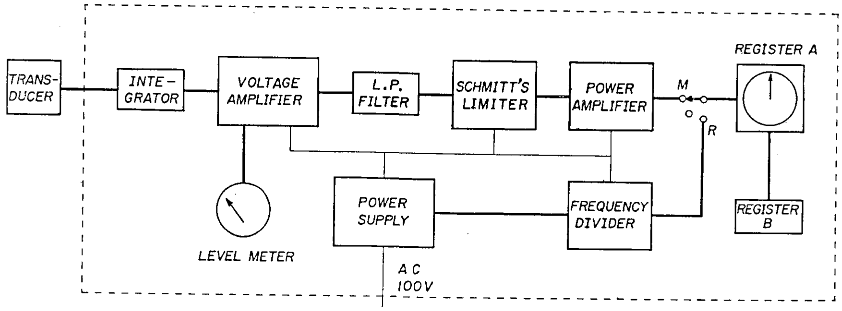


Fig. 3. Block diagram showing the constitution of the natural period meter.

The operation of the natural period meter may be explained as follows. Since in normal times the vibration amplitude on the upper part of buildings is as small as a few microns even in a noisy city, the output signal from the transducer is amplified until there is sufficient voltage to drive the limiter after it has passed through the integrating network. The amplifying circuit provides a gain of approximately 120 db with four cascaded stages which contain two triodes and two pentodes.

The time constant of the RC-integrating network is 1.0 second. The output of the amplifying circuit is fed to the Schmitt type limiter through a RC low-pass filter which is changeable the slope of its characteristic curve on the high frequency side.

As is well known, the Schmitt type limiter transforms the waveform of an input signal into a rectangular wave with a large, constant amplitude, keeping the same period as the signal. For the electromechanical impulse register, a rectangular wave of applied voltage is available to make sure of the operation of the register.

In the period meter, two different types of impulse registers are employed to count the number of waves of the signal, that is, one is a particular pointer type register and the other is an ordinary one with number wheels. The pointer type register was also especially designed by us and the mean period and mean frequency of the signal waves can be read off directly. The register consists of an electro-magnet, a moving-iron bar with a driving claw, a ratchet wheel with a pinion on its shaft, a spur wheel with a pointer and a scale plate. Every time an electric pulse is fed to the magnet coil, the ratchet wheel turns one tooth at a time. The ratchet wheel has 100 teeth and drives the spur wheel with a reduction ratio of 1/10. So the pointer fixed on the spur wheel shaft makes one revolution when 1,000 pulses are fed to the magnet coil. For instance, it takes 100 seconds for the pointer to make one round on a scale plate in the case of the period of the signal being 0.1 second.

The scale is doubled in frequency and period which is the reciprocal of frequency. The range of the two scales are 0 to 10 cycles and 0.1 to 1.0 second for frequency and period, respectively. Therefore, the mean period as well as the mean frequency of the vibration signals can be read directly on the scale plate by operating the register for just 100 seconds. One division of the frequency scale corresponds to 0.1 cycle, and has a length of 2 mm, so the error in frequency reading is not over $\pm$ 0.01 cycle. The resetting of the pointer is done electrically. The register of another type is usually used only when operating time other than 100 seconds is desired.

The standard measuring time of 100 seconds was determined on consideration of the convergence on the values of the mean period measured to the various measuring times. Because the shorter the time, the greater is the degree of influence of accidental disturbances on the measured value. Fig. 4 shows the relation of the mean periods to the various measuring times which were obtained from a reinforced concrete building. In this figure the mean period represents the average of the values measured five times. It will be seen in Fig. 4 that the values considerably tend towards a certain asymptotic value after about 100 seconds.

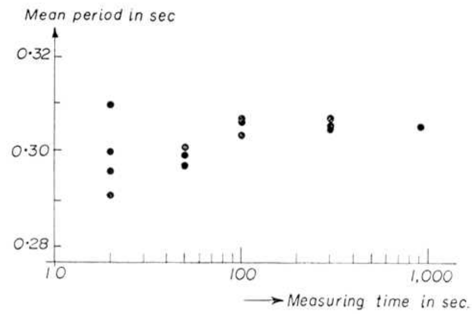


Fig. 4. Relation of the mean period to the measuring time.

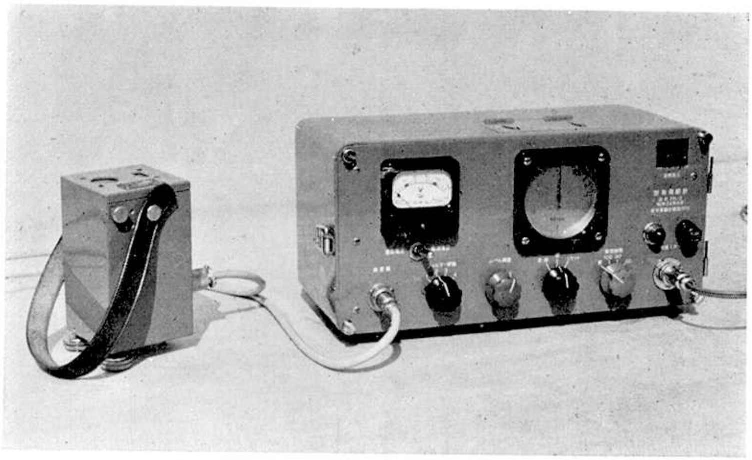


Fig. 5. Natural period meter.

The appearance of the natural period meter is shown in Fig. 5. Although an electron tube has been adopted as an active element in the electric circuits of this period meter, the replacement of the tube with a transistor is not only easy work at present, but also desirable for minimizing the size of the instrument.

4. Examples of measurement

To verify the utility of this natural period meter, practical experiments were carried out on those buildings where experiments with the vibrator method had already been applied. In these measurements the transducer was installed on the upper floor of the buildings. Then the measurements were repeated five times and the average values were adopted as the final results. The mean periods thus measured with the

Table 1.

No.	Name of building	Constr.	Stories	Direction	Periods (sec)		
					Resonance	Predomi.	Mean
1	Komagome	RC	4	NS	0.32	0.31	0.31
2	Senju	〃	〃	〃	0.27	0.27	0.29
3	Ishikawa-chō	〃	〃	〃	0.22	0.21	0.23
4	Totsuka	〃	〃	〃	0.33	0.31	0.31
5	Honmura-chō	〃	〃	〃	0.23	0.21	0.23
6	Gōtokuji	〃	〃	〃	0.32	—	0.32
7	Taishidō	〃	〃	〃	0.32	0.32	0.32
8	Kyōdō	〃	〃	〃	0.32	0.33	0.32
9	Hitachi No. 6	〃	3	〃	0.10	0.10	0.10
10	Hitachi No. 14	〃	〃	〃	0.18	0.18	0.17
11	Kumegawa	〃	5	〃	0.28	0.27	—
12	Nonomiya	〃	7	NS	0.48	—	0.48
				EW	0.38	—	0.40
13	Mampei	〃	4	NS	0.42	—	0.41
				EW	0.40	—	0.38
14	Ōkura	〃	5	NS	0.38	—	0.37
				EW	0.30	—	0.30
15	Mantetsu	〃	6	NS	0.50	—	0.47
				EW	0.44	—	0.39
16	Fuse Middel School	〃	3	NS	0.34	0.32	—
17	Shiratori El. School	〃	〃	〃	0.21	0.25	—
18	Hollywood Storage (U. S. A.)	〃	10	NS	1.20	1.12	—
				EW	0.49	0.49	—
19	Earthq. Res. Inst., Main Bldg.	SRC	2	NS	0.13-0.14	0.13 ?	0.23
				EW	0.18	0.22	0.25
20	Hōsei 53 Nen-kan	〃	6	NS	0.39	—	0.37
				EW	0.57	—	0.56
21	Chūō Kōron	〃	〃	NS	0.51	0.50	—
				EW	0.29	0.31	—
22	Tokyo Metrop., Main Office Bldg.	〃	8	NS	0.59	0.59	—
				EW	0.41	0.43	—
23	Daiichi Seimei	〃	12	NS	0.58	0.47	—
				EW	0.58	0.51	—
24	Midori	〃	9	NS	0.38	—	0.39*
				EW	0.42	—	0.42*
25	Alexander (U. S. A.)	〃	16	NS	1.25	1.25	—
				EW	1.33	1.35	—
26	Earthq. Res. Inst., Bldg. II	M	2	NS	0.24	0.23	0.22
				EW	0.22	0.21	0.20
27	Hosaka	W	〃	NS	0.44-0.49	0.43	0.43
				EW	0.31-0.34	0.30	0.32
28	Nagoya TV Tower	S	(180m)	NS	1.27	1.27	—

RC: Reinforced concrete. SRC: Steel framed reinforced concrete.
S: Steel. M: Mortared frame wooden. W: Wooden.
*) after K. Nakagawa.

period meter, the predominant periods from the period distribution curves and also the resonance periods obtained from the vibration experiments are given in Table 1 with the data relating to the buildings.

It may be said from this comparative table that the results obtained by the period meter coincide well with the ones obtained by the vibrator method, in spite of the fact that buildings greatly differ in dimensions and type of construction.

Fig. 6 shows the percentage residual error of the mean periods to the resonance periods. It will be seen in the figure that about 70 % of the whole buildings treated here have a residual error of less than 5 %. In the case of the residual error running up to 10 % or more, the reason seems to be either that the buildings having complicated shapes or that the two measurements are diametrically different in vibration amplitude.

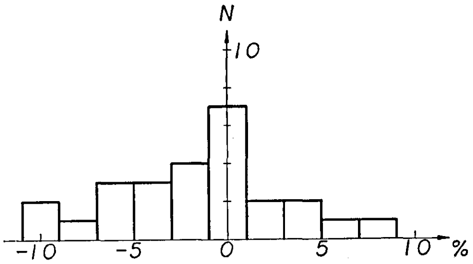


Fig. 6. Relation between the number of measurements and the percentage residual of the mean periods to the resonance periods.

As a matter of fact, usually the vibration amplitude of buildings in normal times is only a few microns or less, while it is not unusual for resonance amplitude in a vibration experiment to amount to a few hundreds of microns. Moreover, it may supports the above reasoning to note that the frequency distribution diagram of the residuals is not symmetrical and is preponderant on the negative side as seen in Fig. 6.

Completion of this instrument has shortened the time required for the measuring of the natural period of buildings. The measurements of both directions of a building have been taken within 20～30 minutes. The accuracy of this instrument for measurement was found to be satisfactory for practical use. The natural period meter is not only useful in measuring buildings but also applicable for other structures, towers, bridges and so on.

5. Acknowledgements

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14. 固 有 周 期 計

地震研究所 田 中 貞 二

建物は，風，土地の常時微動，あるいは交通機関などによる不規則な強制力を受けて，たえず微小な振巾で振動しているので，適当な方法でその振動を解析すれば，建物の固有周期を見出すことができるはずである．

われわれは，構造形式の異る多くの実在建物について，その常時微動を測定し，振動周期の頻度分布から求めた卓越周期の値と，同じ建物の起振機による振動実験から求められている共振周期の値とを比較し，両者がよく一致することを確めた．多くの場合，頻度曲線の形は卓越周期を境に左右がほぼ対称であるので，振動の平均周期を測定すれば建物の固有周期に近い値が得られるはずである．

固有周期計はこのような考えにもとづいて作られたもので，建物における常時微動の平均周期が簡単な操作で測定できるような直読式計器である．試験の結果，測定値の精度，測定能率などの点で，この計器は充分な実用性をもつことが認められた．