13. *On the Damping of Vibration of Actual Buildings. I.*

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1. Introduction.

If there were no movements of damping or dissipation in the vibrations of a structure, it is probable that almost any structure would suffer damage in an earthquake owing to resonance, as actual earthquake movements consist generally of a large range of vibrational periods.

Fortunately, however, we have many kinds of damping and dissipation in a structure on land, so that a structure may be free from resonance even in synchronous vibrations. The question of air resistance and damping in the material used in the structure as well as in the foundation has been studied by some investigators1). The problem of the dissipation of vibrational energy of building in the form of elastic waves transmitted into the ground have been studied theoretically by us. The statistical studies concerning the damage of non-wooden buildings due to earthquake were explained considerably by the results of the theoretical studies based upon the idea of dissipation.

In this investigation, we examined the damping coefficient of many kinds of actual buildings, using the results of vibration experiments by means of vibrator in order to obtain a better insight into the aseismic properties of a structure.

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1) K. SEZAWA, "On the Decay of Waves in Visco-Elastic Solid Bodies", *Bull. Earthq. Res. Inst.*, **3** (1927), 43.

K. SUYEHIRO, "On the Upper Limit of the Frequency of Transverse Vibration of Prismatic Bars", *Proc. Imp. Acad. Japan*, **4** (1928), 286.

K. SUYEHIRO, "On the Damped Transversal Vibration of Prismatic Bars", *Bull. Earthq. Res. Inst.*, **6** (1929), 63.

K. MUTO, "Biegungschwingungen mit Berücksichtigung der Stabmasse und der äusseren und inneren Dämpfung, *ZAMM*, **10** (1930), 346.

J. L. ALFORD and G. W. HOUSNER, "A dynamic test of a four story reinforced concrete building", *Publ. Earthq. Eng. Res. Inst.*, Aug., 1951.

2. Damping ratio of the actual buildings.

Firstly, the following process was used in examining the damping ratio of the actual buildings by means of resonance curves. When a constant force is applied to one mass system, the damping coefficient will be evaluated from the following formula.

$$h=\frac{1}{\sqrt{2}}\sqrt{1-\left\{1+\left(\frac{p_2^2-p_1^2}{2n_0^2}\right)^2\right\}^{-1/2}}, \quad \ldots\ldots\ldots\ldots(1)$$

where, $h=\varepsilon/n$, $\varepsilon=\xi/M$, $n=\sqrt{K/M}$, and ξ, K, M are damping coefficient, stiffness, mass respectively. p_2, p_1 and n_0 are frequencies of resonance curve at $1/\sqrt{2}$ times resonance amplitude and resonance freqnency. Generally speaking, for actual buildings, the value of $|p_2-p_1|/n_0$ is much less than 1, so equation (1) may be transformed as follows;

$$h=(p_2^2-p_1^2)/4n_0^2. \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Damping ratio $v(=e^{\varepsilon T})$ will then be calculated easily by means of equation (2) using the results of vibration experiments, the results are shown in Fig. 1.

It will be seen that, for actual ferro-concrete buildings, the damping ratio increases with the decrease in natural period. This feature

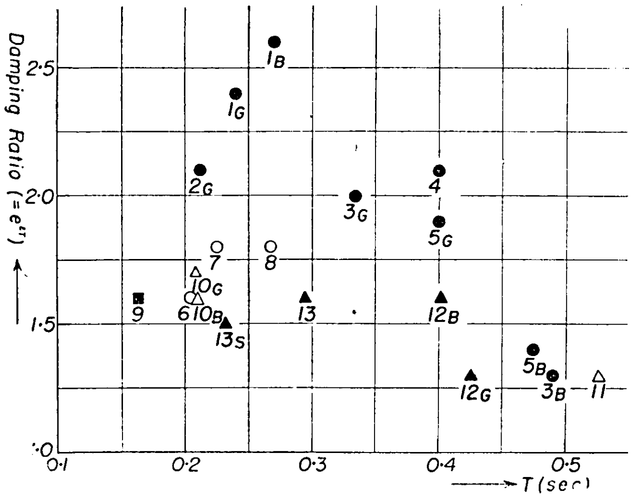

Fig. 1. Relation between the damping ratio and the natural period of actual buildings. Marks ●, ○, △, ▲, ■ and B, G represent ferro-concrete, non-column ferro-concrete, precast ferro-concrete, wooden, concrete block building and beam, girder direction respectively. Mark S reperesents the condition fixed brace-strut.

tells us that the rigid construction in ferro-concrete building is very desirable in preventing earthquake damage. On the other hand, for actual precast ferro-concrete, wooden and brick building, the damping ratio in question scarcely increases with the decrease in natural period, and takes very small value.

3. Damping coefficient of the actual buildings.

Secondly, the following method was used in examining the damping coefficient of the actual buildings. It can be shown that, in a one mass system with damping, the resonance amplitude is given by

$$y_0=\frac{rmn_0^2}{M}\left(\frac{1}{2\varepsilon n_0}\right), \quad \text{.................} (3)$$

where m and r are the eccentric mass and eccentricity of vibrator. From equation (3), we obtain

$$\xi=\frac{\pi rm}{T_0 y_0}. \quad \text{.....................} (4)$$

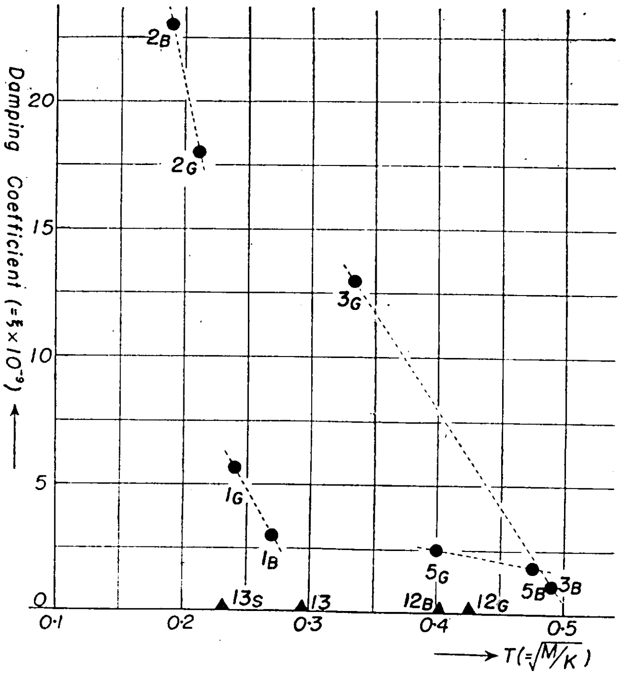

Fig. 2. Relation between the damping coefficient and the natural period of actual buildings. Marks ●, ▲ and B, G represent ferro-concrete, wooden building and beam, girder direction respectively.

Damping coefficient was then calculated by means of equation (4), and the results are given in Fig. 2. In Fig. 2, the relation between the two points connected by broken lines shows that the damping coefficient for the direction of short period is larger than the damping coefficient for long period of the same building. In other words, as the value of mass is constant for two directions of the same building, the damping coefficient of actual building increases with the increase in the vibrational stiffness.

This fact can be explained by the results2) of theoretical studies, based upon the idea that the vibration energy of buildings dissipates to the ground as elastic waves originating from the foundation.

The constants of the buildings as well as the vibrator and the results of experiments are shown in Table I and Table II.

Table I.

No.	Name of Building	Construction	Stories	Plan (m)	Vibrator		
					Eccentricity (cm)	Eccentric mass (kg)	Location (floor)
1	Sanno A	Ferro-concrete fire-damaged	4	12×8	21.5	65	Roof
2	Sanno B		4	20×11.4	〃	〃	〃
3	Aoyama		3	54×11	〃	80	2nd
4	Mampei		4	44.4×21.0	〃	65	4th
5	Nonomiya		7	33×19	〃	〃	7th
6	Takaba No. 6	Non-column ferro-concrete apartment	4	37.9×6.6	〃	〃	Roof
7	Takaba No. 2		4	〃	〃	〃	〃
8	Nishinomiya		4	〃	〃	〃	〃
9	Matsui	Concrete block	2	4.3×3.5	9.0	45.7	2nd
10	Women's Medical College	Precast ferro-concrete	2	28×12	22.5	7.5	〃
11	Examination		2	4×3	5.0	45.7	〃
12	Chitose	Wooden school	2	10×8	11.0	〃	〃
13	Kamakura		1	11×4.6	23.0	1.63	Beam

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2) K. SEZAWA and K. KANAI, "Improved Theory of Energy Dissipation in Seismic Vibrations of a Structure", *Bull. Earthq. Res. Inst.*, **14** (1936), 164.

Table II. Results of vibration experiment. G; girder direction, B; beam direction, (S); the condition fixed brace struts.

No.	Name of Build.	Direction	Resonance			Damping		
			Force (ton)	Period (sec)	Ampl. (mm)	$h(=\varepsilon/n)$	$v(=e^{\varepsilon T})$	$\xi\times10^{-9}$
1	Sanno A	G	0.96	0.24	0.0494	0.14	2.4	5.7
		B	0.76	0.27	0.0748	0.15	2.6	3.0
2	Sanno B	G	1.23	0.212	0.0252	0.11	2.1	18
3	Aoyama	G	0.61	0.334	0.025	0.11	2.0	13
		B	0.28	0.49	0.15	0.042	1.3	1.1
4	Mampei	G	0.35	0.40	0.034	0.12	2.1	2.7
5	Nonomiya	G	0.35	0,40	0.047	0.10	1.9	2.5
		B	0.24	0.475	0.097	0.052	1.4	1.8
6	Takaba No. 6	B	1.33	0.204	0.095	0.070	1.6	4.5
7	Takaba No. 2	B	1.09	0.225	0.160	0.091	1.8	2.2
8	Nishinomiya	B	0.77	0.268	0.155	0.090	1.8	1.8
9	Matsui	G	0.61	0.163	0.76	0.071	1.6	0.16
10	Women's Medical College	G	0.15	0.208	0.100	0.084	1.7	0.48
		B	0.15	0.210	0.167	0.078	1.6	0.33
11	Examination.	G	0.033	0.526	2.6	0.039	1.3	0.081
12	Chitose School	G	0.11	0.426	19.0	0,045	1.3	0.002
		B	0.12	0.402	14.0	0.074	1.6	0.003
13	Kamakura School	(S)	0.027	0.232	0.366	0.068	1.5	0.014
			0.017	0.295	0.920	0.073	1.6	0.004

4. Conclusion.

From the present investigations, it was found that the damping due to air resistance and the inner friction due to visco-elastic property of the materials composing the structure do not appear to dominate the damping in usual cases. But the dissipation of energy of vibrations into the ground seems to play an important part in the prevention of the vibrations of a building.

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13. 實在建物の振動減衰性について 第1報

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實在建物の振動減衰性については，空氣抵抗，材料の粘性抵抗，基礎のプラスチック性，振動勢力の地下逸散などが考えられる．實在建物の振動試驗結果から振動減衰係数を算出してみたところ，同じ建物でも，周期の短い振動方向については，減衰係数が大きいことが見られる．この事實は，振動勢力の地下逸散による減衰性で定性的には説明できるが，その他の原因とすると説明は容易でない．一般に，建物の周期が短くなると振動減衰性が増す傾向を示し，特に鐵筋コンクリート造の場合には著しい．このことは，短周期の建物は耐震的に剛性と減衰性の二重の意味で有利なことを教えるものであろう．

又，鐵筋コンクリート造建物に比べると，組立鐵筋コンクリート造，木造，その他の構造の建物の減衰性は小さい．特に木造の減衰係数の小さいことは（Fig. 2 參照）輕い建物の地下逸散性が小さいという数理的結果に一致するものである．