38. *Model Experiment Confirmations of a Dynamic Method of Minimizing the Seismic Vibrations of a Structure.*

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1. *Introduction.*

In the previous paper[1] we made a suggestion based on theory regarding a dynamic method of minimizing the seismic vibrations of a structure. It was theoretically ascertained that if an inertia mass with suitably selected elastic and viscous resistances were placed within the structure, the amplitudes or stresses in the same structure would be minimized to or below a certain critical for any vibrational frequency of seismic vibrations. The present paper confirms the theory just mentioned by means of model experiments. Since, as already stated, the amplitude of seismic vibrations is particularly large in the horizontal sense, and since moreover the vibration of a structure is most sensible to the same horizontal movement of the ground, the experiments were made specially for the case of horizontal motion.

Although the vibrational forces from the exciter in the present experiments were all of sinusoidal type, yet, owing to the condition that oscillation of an irregular type is nothing more than a combined form of different sinusoidal oscillations, it is possible that the present results apply to the general case to a considerable extent.

2. *The method of experiment.*

The vibration table used in the experiments was the same as that used by Saita (the original one being probably designed by Ishimoto and Takahasi). A hanging table oscillated to and fro by means of periodic forces supplied by a $^1/_4$ H.P. motor through gear arrangement, oil resistances being applied to both sides of the table for flattening the peak of the resonance condition, $T=1{\cdot}175$ sec, of the table vibration.

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1) K. SEZAWA and K. KANAI, "A Method of Minimizing the Seismic Vibrations of a Structure," *Bull. Earthq. Res. Inst.*, **15** (1937), 21~32.

Inasmuch as the periods of vibrations available in our experiments were of the range 0·1 sec to 0·5 sec (though tests were made even for $T=1{\cdot}175$ sec), resonances of such long periods as 1·175 sec were quite immaterial. Since, however, the motor power was not sufficiently high, it was rather difficult to avoid conspicuous changes in the vibration amplitudes of the table for different vibrational frequencies. If, on the other hand, the ratio of the amplitude of the vibration table to that of the structure were taken as we did in our analysis, the difference in the amplitudes of the table for different frequencies would not greatly vitiate the solution of the problem under consideration.

The model for our experiments was a two-storied structure with rigid wooden floors and elastic steel columns. The height below the first floor and that between the first and the second floors were both $l=20$ cm (total height of the structure being 46 cm), whereas the length and width of each floor were 84 cm and 16 cm respectively. The mass to be concentrated on each floor was 4787 gm., the total mass of the structure excepting that of the damper being therefore 9574 gm. The columns in the respective floors consisted of four plate walls, 0·8 mm thick and 12 cm wide with both their ends in approximately clamped condition. The stiffness of the wall columns was found by free vibration tests of the upper floor, using the formula

$$ml^3p^2/EI=12, \tag{1}$$

where EI is the resultant stiffness of the columns in every floor and p the vibrational frequency. The result of the experiment showed that $EI=6{\cdot}587\ kg.\ m^3/sec^2$. The period of free vibration of the whole structure was found to be 0·238 sec. A general view of the structure together with that of the vibration table is shown in Fig. 1.[2)]

The dynamic vibration dampers were of piston type, one of them being made of wood and the other of metal. Although the wooden damper was quite satsfactory, yet owing to its tendency to shrink with time, we used the metal damper for the main experiments. The chamber on the second floor, Fig. 1, is the metal damper and that underneath the same floor the wooden damper. As to the metal damper, the piston that imparts the damping resistance μ' has a mass M supported by the plate spring c. The piston part was reconstructed from a usual static piston damper (probably in Ishimoto's seismograph), but a large sectorial aperture (μ' in Fig. 1) was perforated in the cylinder end in order to obtain the condition of an exceedingly weak

2) T. TAKAYAMA and others kindly assisted us in photographing these and some other data.

Table I.

Case	A	B	C	D	E	F	G
M *in gm*	722	942	1272	1652	2607	3562	5472
$M/(2m)$	0·0755	0·0996	0·133	0·173	0·272	0·372	0·571

viscous resistance in the damper, which proved to be rather efficient as a dynamic damper. The mass M of the damper was of seven kinds, as shown in Table I. The period of free vibration of the damper alone in Case D was roughly 0·26 sec. The aperture at the cylinder end was of five kinds (excepting an auxiliary one 3′) as shown in Table II, the area of the cylinder section being 54·19 cm^2. Since, strictly speaking, the width of gap between the piston and the cylinder was 0·15 mm, the area of the aperture in Case 1 was not exactly zero.

Table II.

Case	1	2	3	3′	4	5
Area of aperture in cm^2	0	0·1469	0·578	1·071	3·106	8·96
Area ratio of aperture-cylinder	0	0·00271	0·01067	0·1976	0·05732	0·1653

The amplitudes and vibrational frequencies were observed with the aid of a smoke cylinder driven by a synchronous motor, the whole contrivance being firmly fixed to the vibration table. The disturbing effects of this motor on the vibration table was found to be negligible.

In the case of forced vibrations, the displacements of the first and second floors and the damper, all relative to the table, besides the displacement of the table itself relative to the room floor, were recorded without magnification on the cylinder revolving once in two minutes. In the case of free vibration, the displacements of both floors in the structure were magnified ten times.

3. *The experiments and their results.*

Although the vibration experiments were made for various combinations of damper mass and aperture of the piston, the elastic resistance of the damper was kept constant throughout the experiments. The cases with which we experimented were

A1, A5, B1, B3, B4, B5, C1, C2, C3, C4, C5, D1, D2, D3,
D4, D5, E1, E2, E3, E4, E5, F1, F2, F3, F4, F5, G1, G2.

The original data recorded on smoked papers were generally of the type shown in Figs. 2a, 2b which exactly correspond to Cases

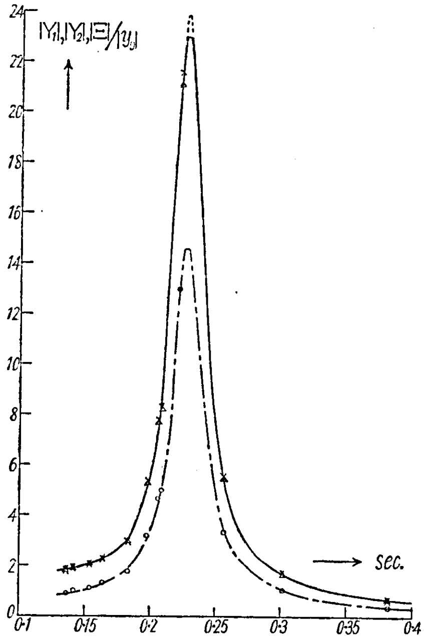

Fig. 3. A1.

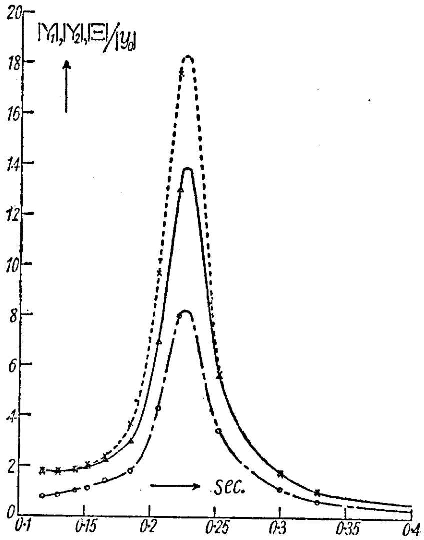

Fig. 4. A5.

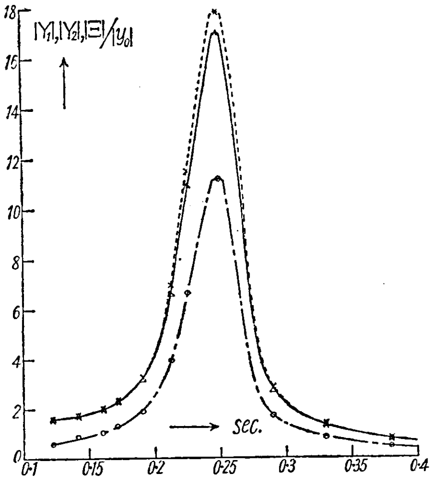

Fig. 5. B1.

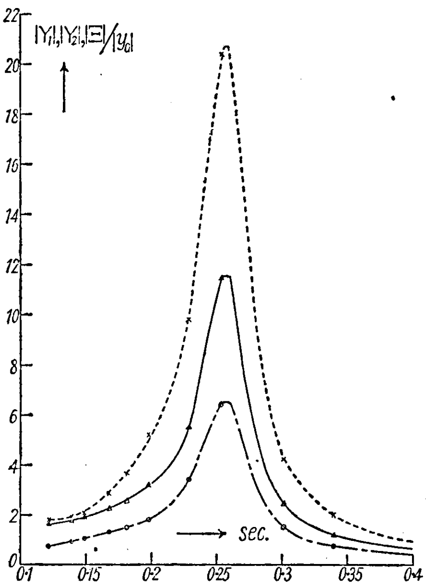

Fig. 6. B3.

A1 ahd D3 respectively. (As will be shown later, Case A1 represents an undamped condition and Case D3 an extremely damped condition.)

All the amplitudes of the respective floors and the damper relative to that of the vibration table as well as the corresponding vibrational

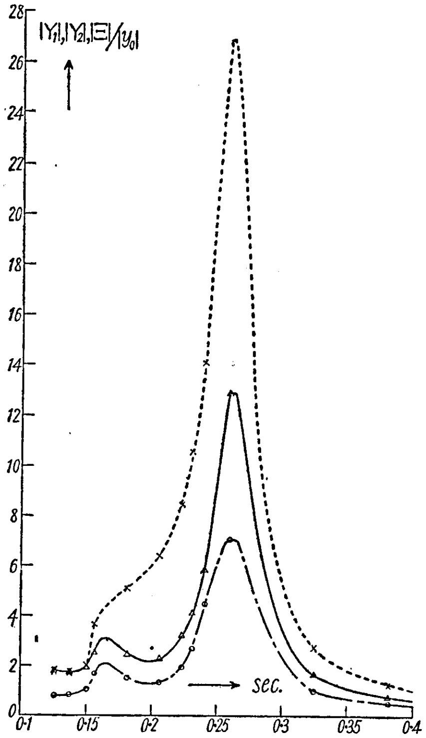

Fig. 7. B4.

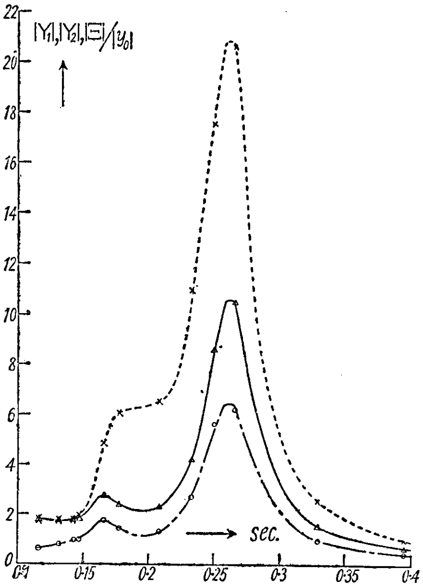

Fig. 8. B5.

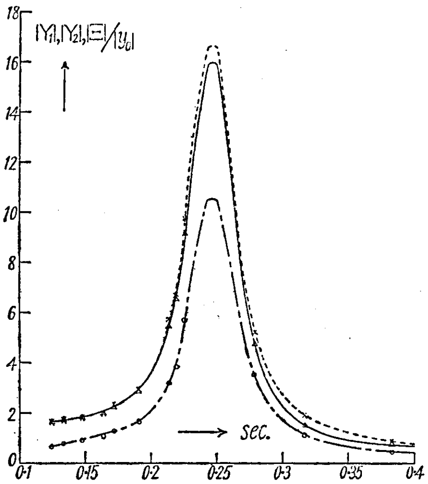

Fig. 9. C1.

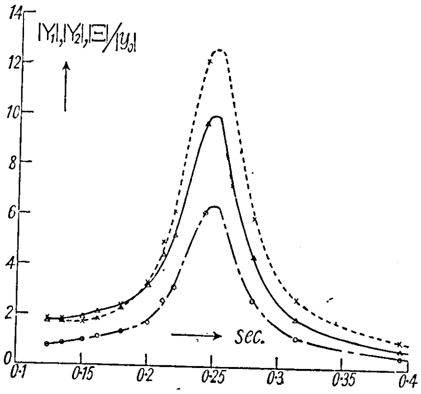

Fig. 10. C2.

frequencies, were read off from records of the type shown in Figs. 2a,

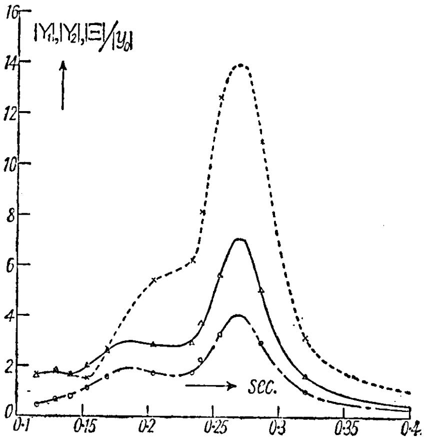

Fig. 11. C3.

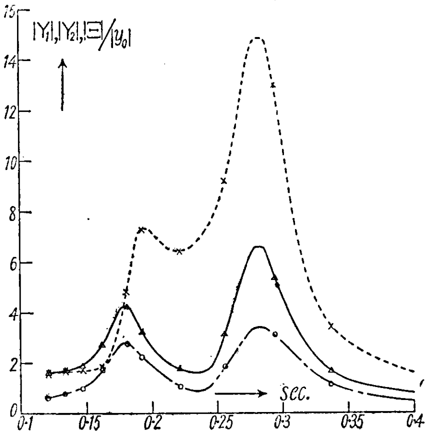

Fig. 12. C4.

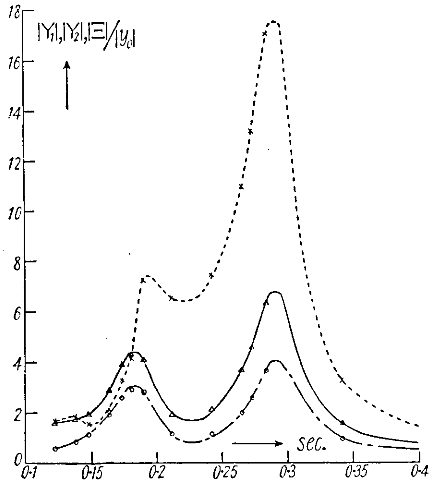

Fig. 13. C5.

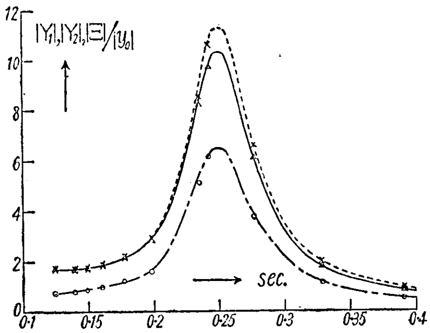

Fig. 14. D1.

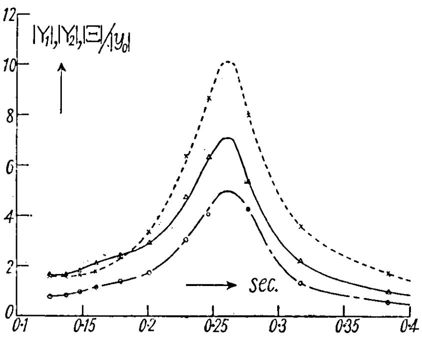

Fig. 15. D2.

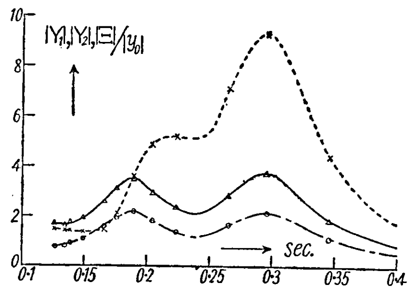

Fig. 16. D3.

2b and the ratios of these amplitudes to that of the table plotted in Figs. 3∼30, which, in the nature of things, represent the resonance curves. It should be borne in mind that the displacement of every one

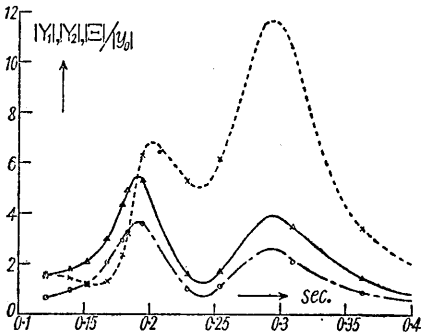

Fig. 17. D4.

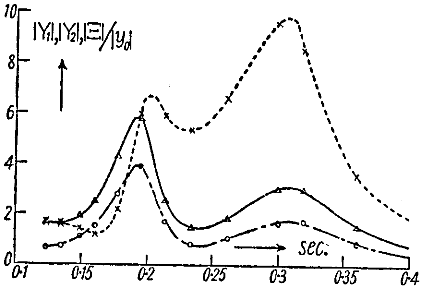

Fig. 18. D5.

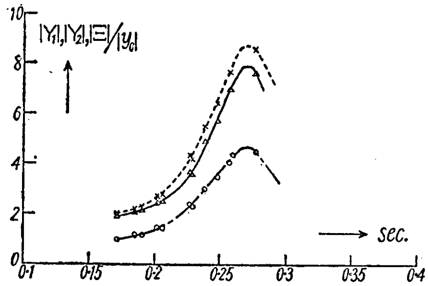

Fig. 19. E1.

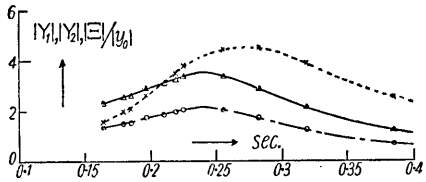

Fig. 20. E2.

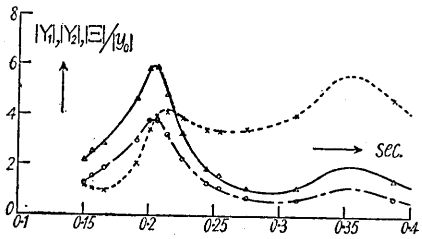

Fig. 21. E3.

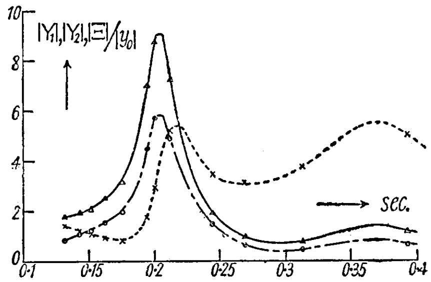

Fig. 22. E4.

of the respective floors and dampers relative to the room space should be the vectorial sum of its recorded amplitude and that of the table. It appears however that the bending moments of the columns are more in line with the relative amplitudes under consideration than with the actual amplitudes. The ratios $|y_1-y_0|/|y_0|$ $(=|Y_1|/|y_0|)$, $|y_2-y_0|/|y_0|$ $(=|Y_2|/|y_0|)$, $|\xi+y_2-y_0|/|y_0|$ $(=|\Xi|/|y_0|)$; namely, the ratios of the relative vectorial amplitudes of the first and second floors and the damper to that of the table, are shown by chain, full, and broken lines in the figures just mentioned.

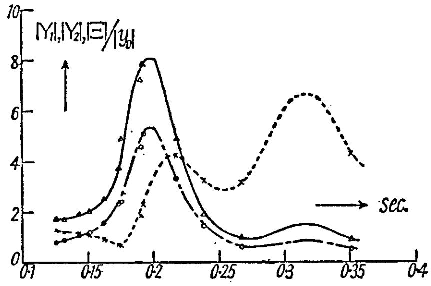

Fig. 23. E5.

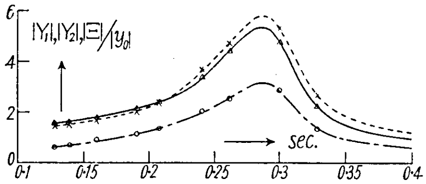

Fig. 24. F1.

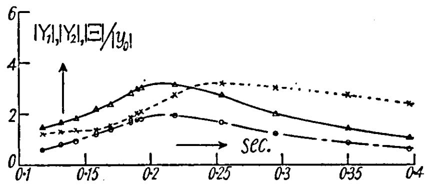

Fig. 25. F2.

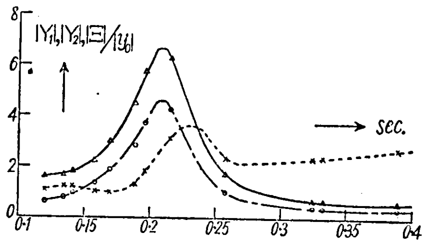

Fig. 26. F3.

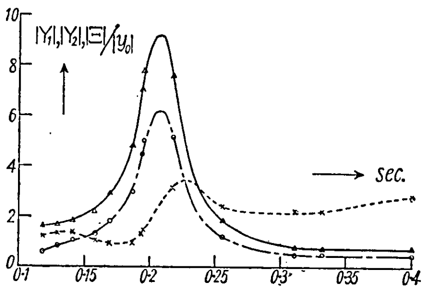

Fig. 27. F4.

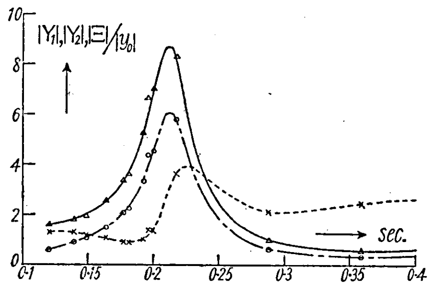

Fig. 28. F5.

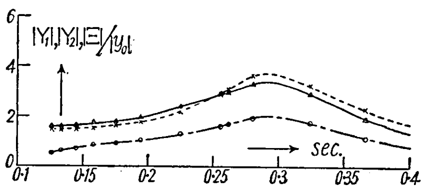

Fig. 29. G1.

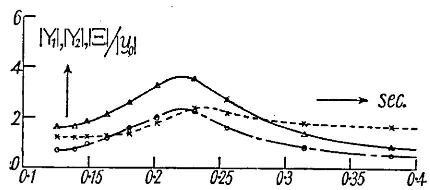

Fig. 30. G2.

Since in Cases A1, B1, C1, D1, E1, F1, G1, the aperture of the damper cylinder was closed, the movement of the damper, particularly in the case of the smaller damper mass, was in such a condition that it was almost fixed to the second floor; see Figs. 3, 5, 9, 14, 19, 24, 29. The data given in these figures represent the resonance curves in the case of an uncoupled vibration. As to resonance conditions of higher frequencies, the problem lies outside the scope of our experiments. The peaks in resonance conditions, however, would be generally pronounced for any area of the aperture were the damper mass extremely small. On the other hand, the fairly flattened peaks in cases wherein the damper mass was exceptionally large, resulted from the effect of the viscous resistance of the air through the gap between the piston and the cylinder. Application of such cases to actual structures, nevertheless, are not practicable owing to the large mass of the damper. The resonance frequency of the approximately uncoupled vibration, as a matter of fact, increased with increase in the damper mass. It is also obvious that unless the damper was effective, the vibration amplitudes would have been extremely large; in Case A1, the ratio of $|y_2-y_0|/|y_0|$ under resonance was even greater than 20.

If the aperture of the damper cylinder were opened, the vibration would then be in a coupled condition. A peak in a resonance curve in the case of uncoupled vibration split into two peaks in a similar curve when the vibration was coupled. With increase in the aperture of the cylinder, the vibrational frequencies of both resonances in coupled vibration differed increasingly from each other, and the sharpnesses of the respective peaks tended to become more pronounced. While, generally speaking, the peak of a long vibrational period was more marked than that of a short one when the damper mass was small, the reverse was the case when the same mass was large.

For a moderate aperture area, the ratios of the vibration amplitudes of the floors to that of the table never exceeded a certain critical. In such a case both peaks in the resonance curve for the amplitude of every floor were likely to be nearly equal. In Case D3, for example, the ratio of the amplitude of the second floor to that of the table under both resonance conditions was less than four. It is thus possible to conclude that with the damper in such a special condition, the ratio of the vibration amplitudes under consideration was never greater than four for any vibrational frequency. It should however be borne in mind that although the state of the second or higher resonance may be another problem for discussion, since other kinds of resistances, say, solid viscosity, etc., took up the largest part of the damping in vibration, there is no need for further comment.

It appears probable that, were the damper of the present type effective in the case of the forced vibration, the free vibration of a structure with the same damper would also be damped very rapidly. With a view to obtaining a thorough insight of this question, free vibration experiments of the model structure were conducted in such a state of the model that the vibration table is fixed to the room floor and the damper pertakes of the vibrational resistance, nearly every case in experiment under forced vibration having been tested in this way. It was shown that damping condition under free vibration fairly conforms with that under forced vibration, that is to say, an effective damper under forced vibration of a structure is also effective in damping its free vibration—a satisfactory condition in an actual case where the seismic vibration of a structure is composed usually of both forced and free vibrations. The results of free vibration tests for Cases A1 and D3′ (nearly equal to condition D3) are shown as examples in Figs. 31a, 31b. It will be seen that although the free vibration in A1 was hardly damped, that in D3′ died away very rapidly (unceasing vibratory tail in Fig. 31b being caused by the small structural movements of the model).

4. *Mathematical theory.*

No mathematical equation corresponding exactly to the present case has yet been formulated. We shall use the mathematical symbols.

l_1, l_2=height of column between the vibration table and the first floor and that between the first and second floors,

E_1I_1, E_2I_2=stiffnesses of the columns above mentioned,

x_1, x_2=coordinates taken along both kinds of columns from their respective lower ends,

y_1, y_2=deflection of columns at x_1, x_2,

m_1, m_2=mass concentrated on the first and second floors,

M, c, μ'=mass, stiffness, and damping constant of the vibration damper,

ξ=horizontal displacement of the mass of the damper relative to the second floor,

$y_0=be^{ipt}$=horizontal displacement of the table.

The solutions of the column deflections are written

$$\left.\begin{aligned} y_1&=(A_1+B_1x_1+C_1x_1^2+D_1x_1^3)\,e^{ip}, \\ y_2&=(A_2+B_2x_2+C_2x_2^2+D_2x_2^3)\,e^{ipt}. \end{aligned}\right\} \qquad (1)$$

The boundary conditions are such that

$$x_1=0;\qquad y_1=be^{ipt},\quad \frac{\partial y_1}{\partial x_1}=0, \tag{(2), (3)}$$

$$x_1=l_1,\quad x_2=0;\qquad \frac{\partial y_1}{\partial x_1}=0,\quad \frac{\partial y_2}{\partial x_2}=0, \tag{(4), (5)}$$

$$y_1=y_2,\quad -E_2I_2\frac{\partial^3 y_2}{\partial x_2^3}=-E_1I_1\frac{\partial^3 y_1}{\partial x_1^3}+m_1\frac{\partial^2 y_1}{\partial t^2}, \tag{(6), (7)}$$

$$x_2=l_2;\qquad \frac{\partial y_2}{\partial x_2}=0,\quad -E_2I_2\frac{\partial^3 y_2}{\partial x_2^3}+m_2\frac{\partial^2 y_2}{\partial t^2}-c\xi-\mu'\frac{\partial \xi}{\partial t}=0, \tag{(8), (9)}$$

$$M\left(\frac{\partial^2\xi}{\partial t^2}+\frac{\partial^2 y_2}{\partial t^2}\right)+c\xi+\mu'\frac{\partial\xi}{\partial t}=0. \tag{10}$$

Writing

$$\gamma_1=\frac{m_1l_1^3p^2}{E_1I_1},\quad \gamma_2=\frac{m_2l_2^3p^2}{E_2I_2},\quad \gamma_3=\frac{(m_2+M)\,l_2^3p^2}{E_2I_2},\quad \eta=\frac{E_2I_2l_1^3}{E_1I_1l_2^3}, \tag{11}$$

and solving (1)$\sim$(10) we get

$$A_1=b,\quad B_1=0,\quad C_1=-\frac{3}{2}l_1D_1,\quad B_2=0\quad C_2=-\frac{3}{2}l_2D_2, \tag{(12)$\sim$(16)}$$

$$\frac{D_1l_1^3\Phi}{2b}=\left[12\eta\left(\gamma_3-\frac{Mp^2}{c}\gamma_2\right)+\gamma_1\left\{(12-\gamma_3)-\frac{Mp^2}{c}(12-\gamma_2)\right\}\right]$$
$$+i\left\{12\eta\frac{\mu'p}{c}\gamma_3+\gamma_1\frac{\mu'p}{c}(12-\gamma_3)\right\}, \tag{17}$$

$$\frac{A_2\Phi}{b}=-12\left[\left\{(12-\gamma_3)-\frac{Mp^2}{c}(12-\gamma_2)\right\}+i\frac{\mu'p}{c}(12-\gamma_3)\right], \tag{18}$$

$$\frac{D_2l_2^3\Phi}{2b}=12\left\{\left(\gamma_3-\frac{Mp^2}{c}\gamma_2\right)+i\frac{\mu'p}{c}\gamma_3\right\}, \tag{19}$$

$$\Phi=\left[12\eta\left(\gamma_3-\frac{Mp^2}{c}\gamma_2\right)-(12-\gamma_1)\left\{(12-\gamma_3)-\frac{Mp^2}{c}(12-\gamma_2)\right\}\right]$$
$$+i\left\{12\eta\frac{\mu'p}{c}\gamma_3-(12-\gamma_1)\frac{\mu'p}{c}(11-\gamma_3)\right\}, \tag{20}$$

from which we get

$$y_{1x_1=l_1}=-\frac{12}{\Phi}\left[\left\{(12-\gamma_3)-\frac{Mp^2}{c}(12-\gamma_2)\right\}+i\frac{\mu' p}{c}(12-\gamma_3)\right], \tag{21}$$

$$y_{2x_2=l_2}=-\frac{12^2 b}{\Phi}\left\{\left(1-\frac{Mp^2}{c}\right)+i\frac{\mu' p}{c}\right\}. \tag{22}$$

Taking the real parts, we have

$$y_0(=y_{1x_1=0})=b\cos pt, \tag{23}$$

$$y_{1x_1=l_1}=-12b\sqrt{\frac{R^2+S^2}{P^2+Q^2}}\cos\left(pt-\tan^{-1}\frac{Q}{P}+\tan^{-1}\frac{S}{R}\right), \tag{24}$$

$$y_{2x_2=l_2}=-12^2 b\sqrt{\frac{R'^2+S'^2}{P^2+Q^2}}\cos\left(pt-\tan^{-1}\frac{Q}{P}+\tan^{-1}\frac{S'}{R'}\right), \tag{25}$$

$$\xi_0=-12^2 b\frac{\dfrac{Mp^2}{c}}{\sqrt{P^2+Q^2}}\cos\left(pt-\tan^{-1}\frac{Q}{P}\right), \tag{26}$$

where

$$\left.\begin{aligned}
&P=12\gamma_1\left(\gamma_3-\frac{Mp^2}{c}\gamma_2\right)-(12-\gamma_1)\left\{(12-\gamma_3)-\frac{Mp^2}{c}(12-\gamma_2)\right\},\\
&Q=\frac{\mu' p}{c}\left\{12\gamma_1\gamma_3-(12-\gamma_1)(12-\gamma_3)\right\},\\
&R=(12-\gamma_3)-\frac{Mp^2}{c}(12-\gamma_2), \qquad S=\frac{\mu' p}{c}(12-\gamma_3),\\
&R'=\left(1-\frac{Mp^2}{c}\right), \qquad\qquad\qquad\quad S'=\frac{\mu' p}{c}.
\end{aligned}\right\} \tag{27}$$

In the special case wherein the stiffness of the columns below the first floor, E_1I_1, is extremely large, the above solutions reduce to those of a one-storied structure as shown in the previous paper[3].

Applying the equations just obtained to such a special case as corresponds to D3 in the experiments, some of numerical data being shown in Secion 2, we obtained the resonance curves as shown in Fig. 32a. In the present case the numerical values obtained in Sections 2 and 3 are such that

3) *loc. cit.* 1).

$$\gamma_1=\gamma_2=0{\cdot}0063\left(\frac{2\pi}{T}\right)^2,\quad \gamma_3=0{\cdot}00811\left(\frac{2\pi}{T}\right)^2,\quad \frac{Mp^2}{c}=\left(\frac{0{\cdot}262}{T}\right)^2,$$

$$\eta=1,\ \frac{\mu' p}{c}=\frac{0{\cdot}065}{T}\ \left(\text{obtained by free vibration tests of the damper}\right),$$

T being the period of forced vibration in sec. The results obtained in the experiments are plotted in Fig. 32b

In the present case, too, the ratios, $|Y_1|/|y_0|$, $|Y_2|/|y_0|$, $|\Xi|/|y_0|$, namely, the relative vectorial amplitudes of the first and second floors and the damper are shown by chain, full, and broken lines respectively. It will be seen that both the results, mathematical and experimental, fairly agree (excepting the large displacement of the damper in mathematical result).

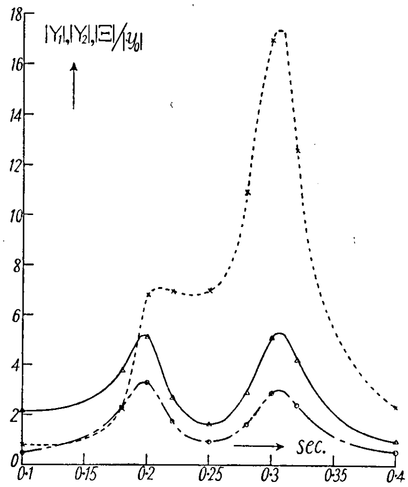

Fig. 32a. D3. Mathematical.

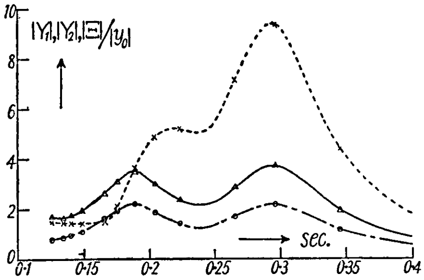

Fig. 32b. D3. Experimental.

Since there are some damping resistances still in the models arising from other causes, such as material damping within the models, etc., perhaps perfect agreement would be rather unreasonable.

5. *Application of the mathematical and experimental results to a full-scale structure and damper.*

It is obvious that any accurate mathematical result should apply to an actual case provided the values of all the numerical constants for both sides are the same. The question may arise whether or not the results of model experiments may be used forthwith in an actual case. A well established law of similitude would eliminate any difficulties in the problem.

As already shown in the theoretical discussion, the parameters required for defining the results are such that

$$\text{(i)} \quad \frac{m_1 l_1^3 p^2}{E_1 I_1}, \quad \frac{m_2 l_2^3 p^2}{E_2 I_2}, \quad \cdots\cdots\cdots, \quad \frac{E_2 I_2 l_1^3}{E_1 I_1 l_2^3}, \quad \cdots\cdots\cdots. \tag{28}$$

$$\text{(ii)} \quad \frac{M}{m}, \quad \frac{E_1 I_1}{m_1 l_1^3} \cdot \frac{M}{c}, \quad \frac{\mu'^2}{Mc}, \tag{29}$$

m being the total mass of the structure. Thus, if these quantities were respectively the same both for the model and the full-scale structure, the results from the model experiments would straightway apply to the full-scale structure.

The conditions in (28) are nothing more than those for the case without damper. Barring structural failures, it is an easy matter, at all events, to obtain such a condition.

The conditions in (29), which are additive, are required in the case with damper. In the case of a (circular) piston type damper, condition (29) may be replaced by

$$\frac{M}{m}, \quad \frac{E_1 I_1}{m_1 l_1^3} \frac{M}{c}, \quad \frac{4\pi S l}{a} \frac{\mu}{Mp}, \tag{29'}$$

S, a, l, μ being piston area, orifice area, orifice length, eddy viscosity of the air respectively. The second item in (29′) is the ratio of the vibration period of the structure to that of the damper.

Our mathematical and experimental results show that the condition of the efficient damper is such that M/m is of the order of 1/10 and the natural vibration period of the damper must be nearly equal to that of the structure, whereas condition, $\mu'^2/Mc=$a constant, is somewhat complex. It is possible to assume that, if p were the same both for the model as well as for the actual structure, $m_1 l_1^3/E_1 I_1$ being the same, $Sl\mu/ap$ should be increased linearly with M, which is not a difficult matter in an actual case.

6. *Concluding remarks.*

From experimental as well as mathematical investigations it has been ascertained that, by a suitable choice of the mass, elastic and damping resistances of the damper, the amplitudes of the seismic vibrations are strongly damped for any vibrational frequency, including those under resonance conditions. The ratio of the damper mass to that of the structure should be of the order of 1/10, which is not too small. But as the viscous resistance required in the dynamic damper of a structure is rather less than what may be expected from the case of a static damper, there is every possibility of applying the present method to the actual case without much difficulty. A practicable method would be to construct a double-walled chamber in the structure, the inner wall of which is supported by some elastic springs so that it will act as a pendulum of nearly the same vibration period as that of the structure. The action of the wooden damper in our model experiments gave us this hint. However, the viscous resistance of the air between the walls would be quite enough for dampening the motion of the structure.

For convenience and in order to expedite our work, in our model for the experiments a number of parts (although with modifications) were adapted from other instruments that were designed by some members of staff in our Institute.

In conclusion we wish to express here our thanks to the Council of the Japan Society of the Promotion of Scientific Research for aid received for conducting these experiments.

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38. 構造物震動の力學的制振法の模型實驗的確め

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前の論文で構造物に力學的制振器を取付ける事によつてその構造物が如何なる振動週期の地震動にも其れの屈曲モーメントや振幅が大きくならずに濟む方法を示して置いた．只今の論文では之を模型實驗によつて確めたのであるが，その場合に用ひたのは 2 階建の構造物の模型であり，その理論も未だ出してなかつたから，數式を新に作り，實驗と比較して見たのである．

振動臺は簡單の爲に地震研究所の方々が試みたやうな吊臺を用ひ，その自己振動週期を避けるやうにした．制振器も簡單の爲に石本博士の地震計等に用ひたピストン式を借用したが，力學的制振器では結局はピストンの粘性力が强過ぎる爲にそれにピストンの直徑の1/10位の大きな穴を作つて初めて効果が現れた．制振器の質量と上記の穴を種々變化して見たが，數式でも出るやうに，制振器に適當の質量，彈性，粘性力を用ひれば，振動臺の如何なる週期の動きに對しても，屋根の振幅が振動臺のそれの四五倍を出ぬ事がわかつたのである．不規則な地震も結局は種々の週期の振動の組合せであるから，之は甚だ好都合な事柄といはればならぬ．

あまり効果のないやうな制振器の組合せに於ける性質も大體に於て數理の結果と一致してをることがわかつた．又，更に大切な事は，制振器か强制振動に對して特に有効な狀態になつてをる場合には，その狀態の制振器を取付けた構造物模型の自由振動も特に著しく制振される事が明か

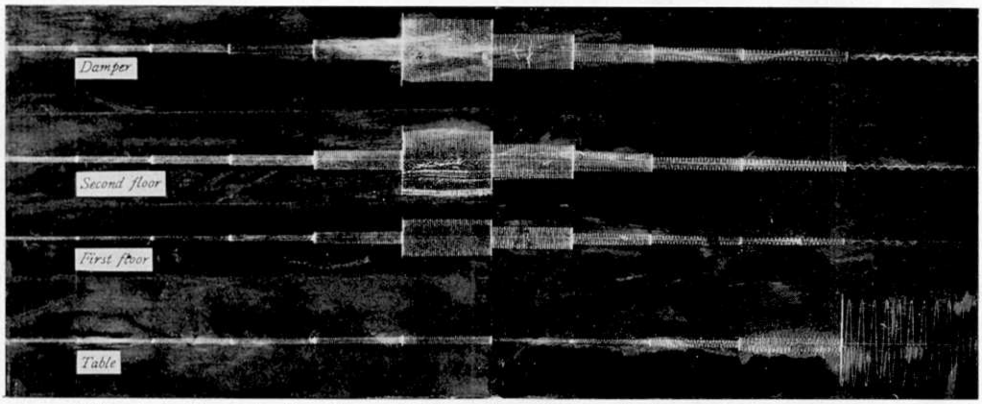

Fig. 2a. Forced vibrations of Case A1. Not well damped. Damper and the second floor vibrate with the same amplitude for any frequency. (Contraction: 1/2)

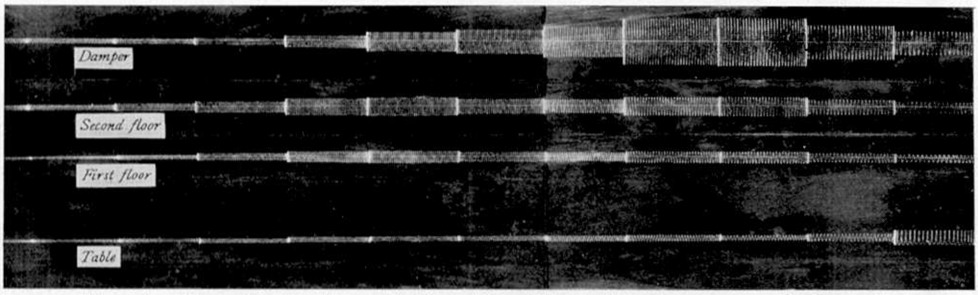

Fig. 2b. Forced vibrations of Case D3. Floor vibrations are well damped for any frequency. (Contraction: 1/2)

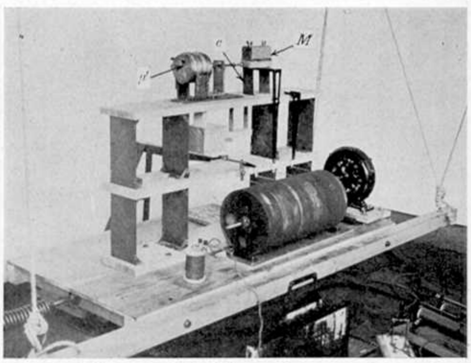

Fig. 1. Model arrangements.

Fig. 31a. Free vibration; A1. Not damped. (Magnif.: 1/2 for damper, 5 for floors.)

Fig. 31b. Free vibration; D3′. Well damped. (Magnif.: 1/2 for damper, 5 for floors.)

(震研彙報 第十五號 圖版 妹澤・金井)

になつたのである．構造物の地震時に於ける振動は強制振動さ思はれるものさその自由振動さ考へられるものさの組合せであるから，如何なる場合にもその効果を表し得る事が考へられる．

理論さ模型實驗さが甚だよく合ふ事は既に述べた通りである．條件さへ同じであれば理論がそのまゝ實物へ應用できる事も當然である．模型實驗を實物にあてはめるには相似の條件が必要である．しかし，構造物の破壞を考へずにその振動性のみを論ずる場合には之亦極く簡單である．制振器がないさきには

$$\frac{m_1 l_1^3 p^2}{E_1 I_1}, \quad \frac{m_2 l_2^3 p^2}{E_2 I_2}, \quad \cdots\cdots, \quad \frac{E_2 I_2 l_1^3}{E_1 I_1 l_2^3}, \quad \cdots\cdots,$$

なる値が模型にも實物にも同じであれば充分であり，且つ之は容易に滿足し得る條件である．制振器があるさ上記のものゝ外に

$$\frac{M}{m}\left(=\frac{\text{制振器の質量}}{\text{構造物の質量}}\right), \quad \frac{T_1}{T}\left(=\frac{\text{制振器の週期}}{\text{構造物の週期}}\right), \quad \frac{\mu'^2}{Mc}$$

がそれぞれ一定であるさいふ條件が加はればよいのである．

模型實驗によるさ，最も効果的の場合は M/m が 1/10 位であり，$T_1/T=1$ である．第3の條件による粘性も可なり小さなものでよい事がわかる．尙，木製の制振器を作つて氣のついた事であるが，實際の制振器の問題さしては物置か何かを二重の壁にし，內側のそれに多少の彈性的支へを作ればよい．壁さ壁さの間の隙間や窓などもそれ程狹くする必要のなさそうなこさもわかつたのである．