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19. *Aseismic Properties of a Wooden House (III).*

By Genrokuro NISHIMURA and Masazi SUZUKI,

Earthquake Research Institute.

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1. Introduction

This paper covers one field of our research with regard to aseismic structure. In the previous papers[1][2], a study was made of the amplitude characteristics such as damping coefficients and natural frequencies that a wooden small house may show during the course of artificial vibration ranging from a small amplitude to a considerably large amplitude. Further the experiment was made on decentering effect (Suzikai effect) to reveal relationship among size of material, quantity, point of application, amplitude and damping coefficient. The observation was made on the effect of a natural earthquake by setting on house and land two sets of seismometers, one strain gauge and two sets of vibroscopes of variable natural frequency and damping factor. According to the results, the predominant period of the house due to earthquake vibration almost coincides with its natural period and the predominant period of model pendulum of the house due to earthquake vibration is in coincidence with that of the house when its natural frequency and damping factor are taken to be the same as that of the house. Further the observation by changing the period and damping factor of the model pendulum reveals that the predominant period is well distributed around the natural frequency of the pendulum, from which it was found that in general the vibration of a house due to earthquake can be represented by that of a pendulum having the same natural frequency and damping factor and its predominant period coinciding with its natural period.

As mentioned above, the measurement of the natural period and damping factor is essential to study the aseismic properties of a structure and it can be obtained either by analysing the results of the meas-

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1) M. SUZUKI and R. SHOJI, "Aseismic Proparties of a Wooden House, (Part I)", *Bull. Earthq. Res. Inst.*, **34** (1956), 381.

2) M. SUZUKI, "Aseismic Properties of a Wooden House, (Part II)", *Bull. Earthq. Res. Inst.*, **36** (1958), 235.

urement which will be made by giving structure artificially a natural or forced vibration or by observing the current vibration or vibration due to a natural earthquake.

Wooden houses or wooden structures have in general a greater rate of increase in the natural period with an increase in amplitude in comparison with reinforced concrete or iron frame structures. The factors that decide the natural period of a wooden structure are dependent on the weight of structural materials, material, wall, each partition, joint and connecting condition of upper and lower member of hozo (枘), but especially the importance of the vital rôle that the upper and lower hozo (枘) of a column would play under greater amplitude vibration is well accepted by the circles concerned. Therefore, in order to make a thorough study of the aseismic properties of such a structure, it is essential to make clear the amplitude characteristics by measuring the natural period and damping factor throughout the range of a smaller to larger amplitude value. In the actual measurement, a certain limitation occurs in the magnitude of amplitude on account of a fear of destroying the concerned structure, relationship between size of structure and force to be applied and sensitivity of the measuring instruments, which is especially true for the house currently being occupied or for those of an important construction.

Various measurements have already been conducted on the vibration of wooden structure or house, the most of them, however, are confined in the range of small amplitude. Among these, there is only one record relating to a large amplitude, that is, the report prepared by Saita[3] under the subject "Destruction Test on a Wooden House", which, as the authors pointed out, is just a summary report of the experiment and does not cover the range of very small amplitude.

The measurement of the vibration of a structure is, as mentioned above, subjected to so many restrictions that very often the measurement at small amplitude range is forced. Thus, it becomes pertinent here to secure any correlation in the vibration characteristics that may exist between the greater amplitude and the results for very small amplitude which have already been sought by many people or will be studied in future too. The purpose of this paper is to make a study on the vibration characteristics in the range of a very small to greater

3) T. SAITA, "Experiments in the Vibration and Destruction of a Wooden Dwelling House", *Bull. Earthq. Res. Inst.*, **17** (1939) 152.

amplitude after carefully and throughly checking the data obtained by Saida on very small amplitudes.

2. Free Vibration Having Different Restoring Force and Damping Factor in Successive Amplitude

A wooden structure subjected to deformation by an external load being applied in one direction will almost resume its original condition upon release of such force, a part of the deformation, however, will become a residual permanent deformation and remain in the structure. Again the structure is subjected to deformation in the same manner as in the first case, the deformation would differ from the previous, and such behaviour would become appreciable with an increase in the magnitude of the force applied. For such structure if it is subjected to a great deformation once, various joint and support points will be loosen with the result that its restoring force is reduced and the natural period thus increases. In other words, these restoring force and natural period would differ according to the hysterisis of the past deformation. Even though when the restoring force before the deformation is of lateral symmetry with regard to the equilibrium position, it would show the different restoring force in either side against the same amount of deformation, if it is subjected a considerably large deformation in one direction, thus its natural period assumes different values laterally. Such a phenomenon can be observed generally in such experiments as the model test of a wooden structure or free vibration test of the actual wooden structure made by the statical deformation toward one direction.

Now in the system of simple mass, designate successive amplitudes, its period and damping factor, $x_1, x_2, \cdots x_i, T'_1, T'_2, \cdots T'_i$ and $h_1, h_2, \cdots h_i$, equation of motion of the system is

$$\frac{d^2x_i}{dt^2}+2\varepsilon_i\frac{dx_i}{dt}+\sigma_i^2x_i=0 . \qquad (1)$$

A function satisfied by differential equation (1) is in general

$$x_i=e^{-\varepsilon_i t}(C_{i1}\cos\sigma'_i t+C_{i2}\sin\sigma'_i t) , \qquad (2)$$

where

$$i=1, 2, \cdots , \qquad \sigma'_i=\sqrt{\sigma_i^2-\varepsilon_i^2}=\sigma_i\sqrt{1-h_i^2} ,$$

$$\sigma_i=2\pi/T_i , \qquad \sigma'_i=2\pi/T'_i .$$

The amplitude of the first vibratory motion x_1 is

$$x_1=e^{-\varepsilon_1 t}(C_{11}\cos\sigma_1' t+C_{12}\sin\sigma_1' t)\ . \tag{3}$$

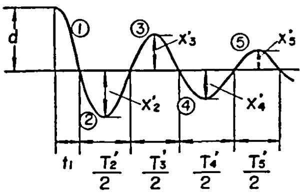

Fig. 1.

When the free vibration is considered by giving an initial deformation d, the initial condition becomes

$$t=0:\quad x_1=d,\quad \text{and}\quad dx_1/dt=0\ . \tag{4}$$

Substituting equation (4) into (3) and its derivative dx_1/dt, then

$$x_1=e^{-\varepsilon_1 t}\frac{\sigma_1 d}{\sigma_1'}\sin(\sigma_1' t+\alpha)\ , \tag{5}$$

where

$$\alpha=\tan^{-1}\left(\frac{\sigma_1'}{\varepsilon_1}\right)=\tan^{-1}(\sqrt{1-h^2}/h)\ .$$

Further,

$$\left.\begin{aligned}\frac{dx_1}{dt}&=-e^{-\varepsilon_1 t}\sigma_1 d\cos(\sigma_1' t+\alpha)\ ,\\ \alpha&=\tan^{-1}(\sqrt{1-h^2}/h)\ .\end{aligned}\right\} \tag{6}$$

Designating t_1 the time at which $x_1=0$, then t_1 and the velocity amplitude at $t=t_1$ are

$$t_1=(\pi-\alpha)/\sigma_1'\ , \tag{7}$$

$$\dot{x}_{1_{t=t_1}}=-\sigma_1 d\cdot\exp\left(-\frac{\varepsilon_1'}{\sigma_1'}(\pi-\alpha)\right)=-\sigma_1 d\cdot\exp\left(-\frac{h}{\sqrt{1-h^2}}(\pi-\alpha)\right)\ . \tag{8}$$

Therefore, if h can be determined by measuring t_1, σ_1' can also be obtained, and finally T_1' can be calculated.

Next, the amplitude x_2 for the second vibratory motion is

$$x_2=e^{-\varepsilon_2 t}(C_{21}\cos\sigma_2' t+C_{22}\sin\sigma_2' t)\ , \tag{9}$$

and as this vibrations supposed to start at the initial condition,

$$t=t_1=\frac{1}{\sigma_1'}(\pi-\alpha)\ ,\quad x_2=0\ ,\quad \frac{dx_2}{dt}=\frac{dx_1}{dt}=-\sigma_1 d\exp\left(-\frac{h}{\sqrt{1-h^2}}(\pi-\alpha)\right)\ ,$$

thus,

$$\left.\begin{aligned} C_{21}\cos\gamma_2+C_{22}\sin\gamma_2=0\ , \\ \gamma_2=\sigma_2'/\sigma_1'\cdot(\pi-\alpha)\ . \end{aligned}\right\} \tag{10}$$

The velocity amplitude dx_2/dt is

$$\left(\frac{dx_2}{dt}\right)_{t=\pi-\alpha/\sigma_1'}=-\sigma_1 d\exp\left(-\frac{\varepsilon_1(\pi-\alpha)}{\sigma_1'}\right)\ .$$

Thus,

$$-C_{21}(\varepsilon_2\cos\gamma_2+\sigma_2'\sin\gamma_2)+C_{22}(\sigma_2'\cos\gamma_2-\varepsilon_2\sin\gamma_2)=-\sigma_1 d\ \exp\left(\frac{\pi-\alpha}{\sigma_1'}(\varepsilon_2-\varepsilon_1)\right)\ . \tag{11}$$

From equations (10) and (11), the values C_{21} and C_{22} can be obtained, namely,

$$C_{21}=\frac{\eta_2\sigma_1 d}{\sigma_2'}\sin\gamma_2\ ,$$

and

$$C_{22}-=\frac{\eta_2\sigma_1 d}{\sigma_2'}\cos\gamma_2\ ,$$

where

$$\eta_2=\frac{\pi-\alpha}{\sigma_1'}(\varepsilon_2-\varepsilon_1)\ . \tag{12}$$

Substituting equation (12) into (9),

$$x_2=-\frac{\eta_2\sigma_1 d}{\sigma_2'}e^{-\varepsilon_2 t}\sin(\sigma_2' t-\gamma_2)\ , \tag{13}$$

and the velocity amplitude dx_2/dt is

$$\frac{dx_2}{dt}=-\frac{\eta_2\sigma_1 d}{\sigma_2'}e^{-\varepsilon_2 t}\left\{-\varepsilon_2\sin(\sigma_2' t-\gamma_2)+\sigma_2'\cos(\sigma_2' t-\gamma_2)\right\}\ . \tag{14}$$

When x_2 assumes its maximum, $dx_2/dt=0$, i.e., putting $t=t_2'$, from

$$\varepsilon_2\sin(\sigma_2' t_2'-\gamma_2)=\sigma_2'\cos(\sigma_2' t_2'-\gamma_2)\ ,$$

$$\tan(\sigma_2' t_2' - \gamma_2) = \frac{\sigma_2'}{\varepsilon_2} = \frac{\sqrt{1-h^2}}{h},$$

thus,

$$t_2' = \frac{1}{\sigma_2'}\left(\tan^{-1}\frac{\sqrt{1-h^2}}{h} + \gamma_2\right).$$

The amplitude x_2' corresponding to the maximum value of x_2 is

$$x_2' = -\frac{\eta_2\sigma_1 d}{\sigma_2'}\exp\left\{-\frac{h}{\sqrt{1-h^2}}\left(\tan^{-1}\frac{\sqrt{1-h^2}}{h} + \gamma_2\right)\right\}\sin\left(\tan^{-1}\frac{\sigma_2'}{\varepsilon_2}\right).$$

Putting $\gamma_2' = \tan^{-1}(\sigma_2'/\varepsilon_2)$, $\sin\gamma_2' = \tan\gamma_2'\cos\gamma_2'$ and

$$\cos\gamma_2' = \frac{1}{\sqrt{1+\tan^2\gamma_2'}} = \frac{\varepsilon_2}{\sqrt{\sigma_2'^2+\varepsilon_2^2}} = \frac{\varepsilon_2}{\sigma_2}.$$

$$\therefore \quad \sin\left(\tan^{-1}\frac{\sigma_2'}{\varepsilon_2}\right) = \frac{\sigma_2'}{\varepsilon_2}\cdot\frac{\varepsilon_2}{\sigma_2} = \frac{\sigma_2'}{\sigma_2}.$$

Therefore,

$$x_2' = -\frac{\eta_2\sigma_1 d}{\sigma_2}\cdot\exp\left\{-\frac{h}{\sqrt{1-h^2}}\left(\tan^{-1}\frac{\sqrt{1-h^2}}{h} + \gamma_2\right)\right\}. \quad (15)$$

The time t_3, at which x_2 again becomes zero, is

$$\sin(\sigma_2' t_3 - \gamma_2) = 0.$$

Namely,

$$t_3 = \frac{\pi+\gamma_2}{\sigma_2'}.$$

Thus,

$$\left(\frac{dx_2}{dt}\right)_{(t=t_3)} = \eta_2\sigma_1 d\exp\left(-\frac{h}{\sqrt{1-h^2}}(\pi+\gamma_2)\right). \quad (16)$$

The amplitude x_3 for the third vibratory motion is, as before,

$$x_3 = e^{-\varepsilon_3 t}(C_{31}\cos\sigma_3' t + C_{32}\sin\sigma_3' t),$$

and as this vibration starts at the initial condition,

$$t=\frac{\pi+\gamma_2}{\sigma_2'}\,, \qquad x_3=0\,, \qquad \frac{dx_3}{dt}=\frac{dx_2}{dt}=\eta_2\sigma_1 d\exp\left(-\frac{h(\pi+\gamma_2)}{\sqrt{1-h^2}}\right),$$

thus the necessary elements can be calculated in the same way as in the second motion as above. Thus x_3 assumes the following form:

$$\left.\begin{aligned} &x_3=\frac{\eta_2\eta_3\sigma_1 d}{\sigma_3'}e^{-\varepsilon_3 t}\sin(\sigma_3' t-\gamma_3)\,,\\ &\text{where,}\\ &\eta_3=\exp\left\{\frac{\pi+\gamma_2}{\sigma_2'}(\varepsilon_3-\varepsilon_2)\,,\qquad \gamma_3=\frac{\sigma_3'}{\sigma_2'}(\pi+\gamma_2)\,.\right. \end{aligned}\right\} \tag{17}$$

The time at which x_3 assumes the maximum and its value are

$$\left.\begin{aligned} &t_3=\frac{1}{\sigma_3'}\left(\tan^{-1}\frac{\sigma_3'}{\sigma_2'}+\gamma_3\right),\\ &x_3'=\frac{\eta_2\eta_3\sigma_1 d}{\sigma_3}\exp\left\{\frac{h}{\sqrt{1-h^2}}\left(\tan^{-1}\frac{\sqrt{1-h^2}}{h}+\gamma_3\right)\right\}. \end{aligned}\right\} \tag{18}$$

And the velocity amplitude dx_3/dt at $t=\pi+\gamma_3/\sigma_3'$ is,

$$\left(\frac{dx_3}{dt}\right)_{t=\pi+\gamma_3/\sigma_2'}=-\eta_2\eta_3\sigma_1 d\cdot\exp\left\{-\frac{h}{\sqrt{1-h^2}}(\pi+\gamma_3)\right\}. \tag{19}$$

Just as being discussed above, x_4, x_5, etc. can be calculated and in general for i-suffix values,

$$\left.\begin{aligned} &x_i=\frac{\eta_2\eta_3\cdots\eta_i\sigma_1 d}{\sigma_i'}e^{-\varepsilon_i t}\sin(\sigma_i' t-\gamma_i)\,,\\ &\text{where}\\ &\eta_i=\exp\left\{\frac{\pi+\gamma_{i-1}}{\sigma_{i-1}'}\right\}(\varepsilon_i-\varepsilon_{i-1})\,,\qquad \gamma_i=\frac{\sigma_i'}{\sigma_{i-1}'}(\pi+\gamma_{i-1})\,,\\ &\qquad\text{and}\qquad i=2,3,4,\cdots. \end{aligned}\right\} \tag{20}$$

$$\left.\begin{aligned} &\text{And}\\ &x_i'=\frac{\eta_1\eta_2\cdots\eta_i\sigma_1 d}{\sigma_{i-1}}\cdot\exp\left\{\frac{h}{\sqrt{1-h^2}}\left(\tan^{-1}\frac{\sqrt{1-h^2}}{h}+\gamma_i\right)\right\},\\ &\text{where}\\ &\eta_i=\exp\left\{\frac{\pi+\gamma_i-1}{\sigma_{i-1}'}(\varepsilon_i-\varepsilon_{i-1})\right\}, \end{aligned}\right\} \tag{21}$$

$$\left.\begin{aligned} &\gamma_i=\frac{\sigma_i'}{\sigma_{i-1}'}(\pi+\gamma_{i-1})\,, \\ &\text{and} \qquad i=1,2,3,\cdots . \end{aligned}\right\}$$

The successive amplitude ratio v_1, v_1, $\cdots$, v_i are

$$\left.\begin{aligned} &v_1=|x_1|/|x_2|=\frac{\sigma_2}{\eta_2\sigma_1}\exp\left\{\frac{h}{\sqrt{1-h^2}}\left(\tan^{-1}\frac{\sqrt{1-h^2}}{h}+\gamma_2\right)\right\}, \\ &v_2=|x_2|/|x_3|=\frac{\eta_2\sigma_3}{\eta_3\sigma_2}\exp\left\{\frac{h}{\sqrt{1-h^2}}(\gamma_3-\gamma_2)\right\}, \\ &\cdots\cdots, \\ &v_{i-1}=|x_{i-1}|/|x_i|=\frac{\eta_{i-1}\sigma_i}{\eta_i\sigma_{i-1}}\exp\left\{\frac{h}{\sqrt{1-h^2}}\left(\gamma_i-\gamma_{i-1}\right)\right\}. \end{aligned}\right\} \quad (22)$$

When $\sigma_1=\sigma_2=\cdots=\sigma_i$, then $\gamma_i-\gamma_{i-1}=\pi$ and $\eta_i=1$, thus, $v_1=v_2=\cdots=v_{i-1}=e^{\frac{\pi h}{\sqrt{1-h^2}}}$; or when ε_1, ε_2, $\cdots$, ε_i are equal to zero, i.e., $h=0$, then $\eta_2=\eta_3=\cdots=\eta_i=1$, thus,

$$v_1=\frac{\sigma_2}{\sigma_1}=\frac{T_1}{T_2}\,,\qquad v_2=\frac{\sigma_3}{\sigma_2}=\frac{T_2}{T_3}\,,\qquad \cdots\,,\qquad v_{i-1}=\frac{\sigma_i}{\sigma_{i-1}}=\frac{T_{i-1}}{T_i}\,. \quad (23)$$

3. Free Vibration of Actual House Under Large Amplitude

Here the relationships obtained above will be applied to the experimental results of an actual house subjected to free vibrations of larger amplitude. The house[4] undergoing the experiment was a tile roof wooden small residential house of $13.2\times7.3\,\text{m}^2$ (24 tsubo) floor area. Fig. 2 is a record of the free vibration of the test house, showing A-component at 2.5 m high and the free vibration was given by releasing the load suddenly. The value P of load is that of the horizontal component of the A-component of the load at the point of application. Table 1 shows amplitudes and periods directly read from the original record of the free vibration, their averages, and the amplitude ratios obtained therefrom. And figures shown in the column of 1st, 2nd, $\cdots$ vibration are corresponding to the maximum amplitudes x_1', x_2', $\cdots$ and the values t_1, $T_2'/2$, which represent the period. Though the value of T_1' is not shown

4) *loc, cit.*, 3).

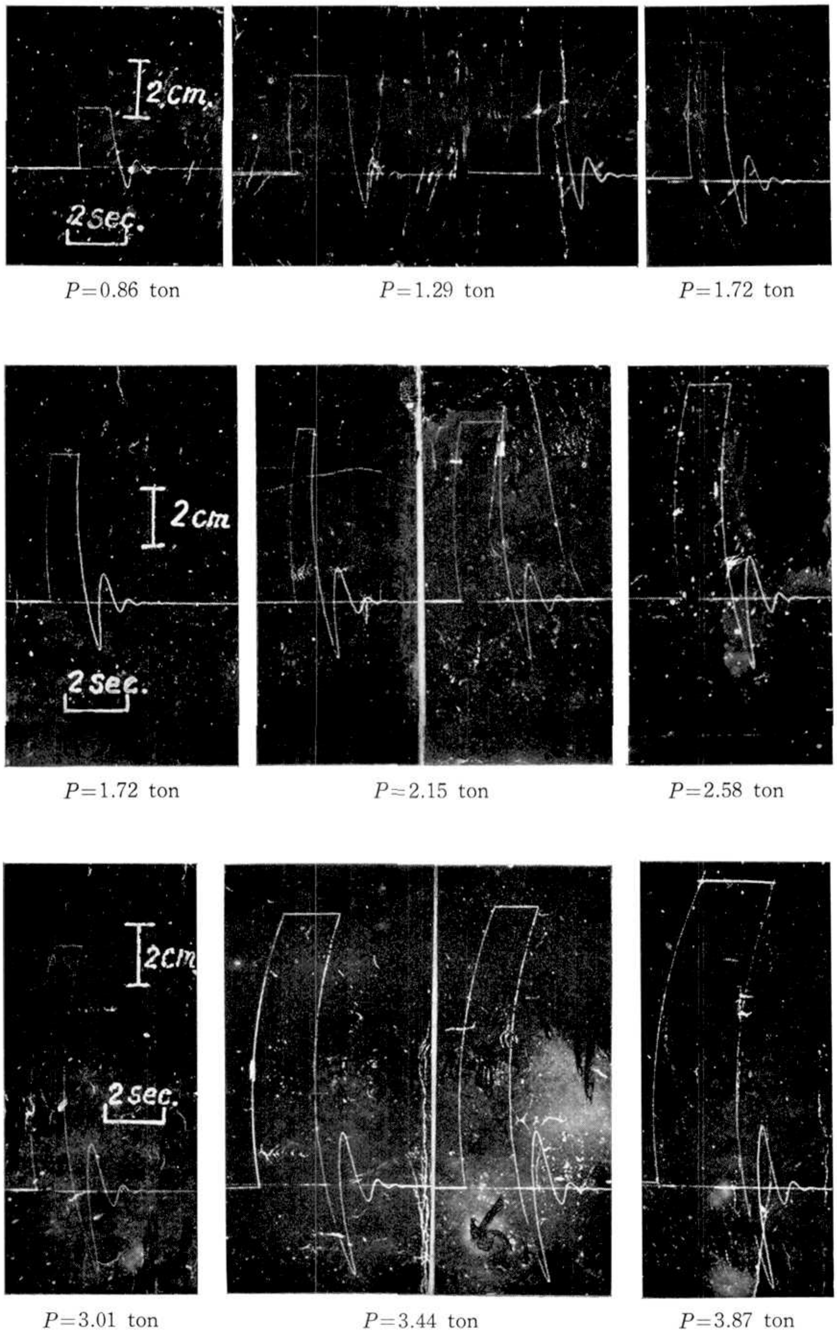

Fig. 2. Records of free vibration of the wooden house. *P*: tensile loads.

Table 1. Amplitudes and periods directly read from original records of the free vibration.

Load (kg.)	No.	A			B			C			D			E			F		R
		x_1'	t_1	v_1	x_2'	T_2'	v_2	x_3'	T_3'	v_3	x_4'	T_4'	v_4	x_5'	T_5'	v_5	x_6'	T_6'	(mm)
		mm	sec.		mm	sec.		mm	mm		mm	sec.		mm	sec.		mm	sec.	
430	No. 1	5.4	0.362		1.6	0.56		0.6	0.38		0.4	0.40							⊕ 6.0
	No. 2	6.6	0.218		2.0	0.62		0.9	0.50		0.4	0.36							0
	mean	6.0	0.290	3.3	1.8	0.59	2.2	0.8	0.44	2.0	0.4	0.38							
860	No. 1	19.0	0.342		5.8	0.72		2.8	0.64		0.8	0.61		0.6	0.42		0.2	0.42	⊖ 0.2
	No. 2	21.2	0.304		6.8	0.77		2.6	0.72		1.2	0.57		0.4	0.44		0.2	0.42	⊖ 0.4
	mean	20.1	0.323	3.2	6.3	0.75	2.3	2.7	0.68	2.7	1.0	0.59	2.0	0.5	0.43	2.5	0.2	0.42	
1290	No. 1	30.0	0.304		11.3	0.76		5.8	0.96		1.8	0.60		0.7	0.59		0.3	0.42	⊖ 0.8
	No. 2	34.6	0.352		12.0	0.76		6.2	0.88		2.0	0.68		0.7	0.53		0.3	0.46	⊖ 0.1
	mean	32.3	0.328	2.8	11.7	0.76	2.0	6.0	0.92	3.2	1.9	0.67	2.7	0.7	0.56	2.5	0.3	0.44	
1720	No. 1	47.6	0.352		15.6	0.76		9.0	0.99		2.8	0.72		1.2	0.57		0.5	0.49	⊖ 1.2
	No. 2	48.8	0.333		16.8	0.80		10.0	1.09		3.0	0.72		1.2	0.53		0.4	0.49	⊖ 0.6
	mean	48.2	0.342	3.0	16.2	0.78	1.7	9.5	1.04	3.3	2.9	0.72	2.4	1.2	0.55	2.8	0.45	0.49	

(to be continued)

(continued)

2150	No. 1	60.6	0.344		19.2	0.77		11.8	1.18		3.6	0.88		1.4	0.60		0.5	0.53	⊖ 0.1
	No. 2	62.4	0.333		20.4	0.83		12.4	1.18		3.6	0.84		1.4	0.60		0.5	0.53	⊖ 1.0
	mean	61.5	0.338	3.1	19.8	0.80	1.6	12.1	1.18	3.4	3.6	0.86	2.6	1.4	0.60	2.8	0.5	0.53	
2580	No. 1	73.0	0.304		23.4	0.84		14.4	1.11		4.2	0.76		1.5	0.65		0.6	0.53	⊖ 1.2
	No. 2	74.6	0.361		24.6	0.92		14.8	1.21		4.8	0.78		1.6	0.61		0.7	0.53	⊖ 0.6
	mean	73.8	0.333	3.1	24.0	0.88	1.6	14.6	1.16	3.7	4.5	0.77	2.8	1.6	0.63	2.5	0.65	0.53	
3010	No. 1	85.2	0.380		27.4	0.98		16.6	1.18		5.5	0.91		1.9	0.68		0.5	0.56	⊖ 0.5
	No. 2	84.6	0.374		26.8	0.87		16.8	1.18		5.5	0.87		1.8	0.72		0.6	0.53	⊕ 0.6
	mean	84.9	0.377	3.1	27.1	0.93	1.6	16.6	1.18	3.0	5.5	0.89	2.9	1.9	0.70	3.5	0.55	0.55	
3440	No. 1	95.6	0.371		31.4	0.99		18.0	1.25		5.6	0.95		1.8	0.72		0.7	0.57	⊕ 1.0
	No. 2	98.6	0.380		32.8	0.93		19.8	1.32		5.8	0.87		2.0	0.70		0.6	0.47	⊖ 0.2
	mean	97.1	0.376	3.0	32.1	0.96	1.7	18.9	1.29	3.3	5.7	0.92	3.0	1.9	0.71	2.9	0.65	0.52	
3870	No. 1	104	0.437		34.8	1.01		21.2	1.27		5.8	0.85		2.0	0.76		0.6	0.57	⊖ 0.5
	No. 2	109	0.399		34.4	0.91		20.6	1.32		5.6	0.99		2.0	0.80		0.6	0.53	⊕ 0.7
	No. 3	108	0.418		35.6	1.04		20.0	1.33		5.7	0.87		1.9	0.80		0.6	0.57	⊖ 0.6
	mean	107	0.418	3.1	34.9	0.99	1.7	20.6	1.31	3.6	7.7	0.90	2.9	2.0	0.79	3.3	0.6	0.56	

note: 1. $v_1=x_1'/x_3'$, $v_2=x_2'/x_3'$....... 2. R: residual permanent deformation. ⊕.... x_1', x_3'...., ⊖.... x_2', x_4',.... side.
3. A, B, C,.... first, second, third amplitude respectively.

on the Table 1, it can be obtained from the relationship, $T_1'=2\pi t_1\bigg/\left(\pi-\tan^{-1}\dfrac{\sqrt{1-h^2}}{h}\right)$, it is smaller value than $4t_1$ and it decreases with a decrease in the value of damping factor. Table 2 indicates the

Table 2. $T_1'=2\pi t_1\bigg/\left(\pi-\tan^{-1}\dfrac{\sqrt{1-h^2}}{h}\right)$.

h \ t_1	sec. 0.418	sec. 0.376	sec. 0.377	sec. 0.333	sec. 0.338	sec. 0.342	sec. 0.328	sec. 0.323	sec. 0.290
0	sec. 1.67	sec. 1.51	sec. 1.51	sec. 1.33	sec. 1.35	sec. 1.37	sec. 1.31	sec. 1.24	sec. 1.16
0.1	1.63	1.42	1.42	1.25	1.27	1.29	1.23	1.17	1.09
0.2	1.51	1.36	1.36	1.20	1.21	1.23	1.18	1.11	1.04
0.3	1.41	1.26	1.26	1.11	1.13	1.15	1.10	1.08	0.97
0.4	1.33	1.19	1.19	1.06	1.07	1.09	1.04	1.02	0.92
0.5	1.26	1.13	1.13	1.00	1.01	1.03	0.98	0.97	0.87
0.6	1.19	1.07	1.07	0.95	0.96	0.97	0.93	0.92	0.82
0.8	1.05	0.95	0.95	0.84	0.85	0.86	0.83	0.82	0.73

value of T_1' obtained from t_1, in which the greater value of T_3 is remarkably noticed in a larger range of amplitude when the period of free vibration for each load is observed. For example, at 3.87 ton of load, T_1', T_2', T_3', $\cdots$ are 1.51 sec (from $T_1'=2\pi t\bigg/\left(\pi-\tan^{-1}\dfrac{\sqrt{1-h^2}}{h}\right)$, at $h=0.2$) 0.99 sec, 1.31 sec, 0.90 sec, $\cdots$ respectively, which against all loads is in a same trend, as the relationship $T_1'>T_2'<T_3'$ is observed.

The damping ratios v_1, v_2, $\cdots$ are nearly of constant value except in the range of very small load, i.e., they are 2.8~3.1, 2.0~1.6 and 3.0~3.7 respectively and the damping of x_2 is extremely great in comparison with x_3, which may be attributed to the decrease in the restoring force to the direction along which a considerably large amount of the deformation was given under the free vibration. Figs. 3~6 show the relationships of x_2', x_3', x_4' against h which were obtained by giving t_1, T_2', T_3', T_4' and the mean value of $x_1'=d$ to the value of x_i' in equation (21) against four values of load varying 3.87 ton~0.86 ton. The circle mark indicates the observed value of x_2', x_3' and x_4' respectively. For 0.86 tons of load, the calculated and experimented values of x_2', x_3' and x_4' coincide at the value of damping factor $h=0.23$; for 1.72 tons load, at $h=0.21$, 0.23 and 0.25; for 3.01 tons load, at $h=0.23$, 0.24, 0.26; for 3.78 tons load, at $h=0.21$, 0.23, and 0.25 respectively. Thus the damping

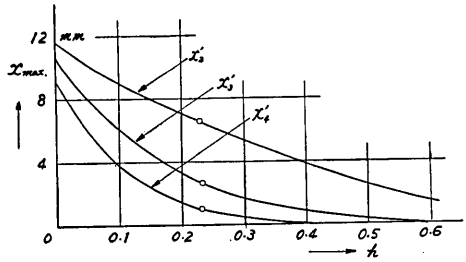

Fig. 3. The case of $x_1'=20.1$ mm, $t_1=0.320$ sec, $T_2'=0.75$ sec, $T_3'=0.68$ sec $T_4'=0.59$ sec. ○: Observed values of x_2', x_3' and x_4' respectively.

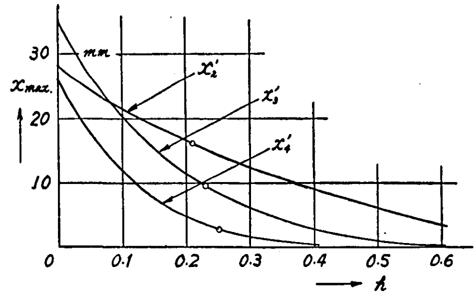

Fig. 4. The case of $x_1'=48.2$ mm, $t_1=0.340$ sec, $T_2'=0.78$ sec, $T_3'=1.04$ sec, $T_4'=0.72$ sec. ○: Observed values of x_2', x_3' and x_4'. respectively.

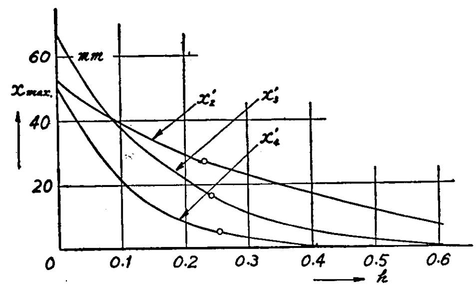

Fig. 5. The case of $x_1'=84.8$ mm, $t_1'=0.377$ sec, $T_2'=0.93$ sec $T_3'=1.18$ sec, $T_4'=0.89$ sec. ○: Observed values of x_2', x_3' and x_4' respectively.

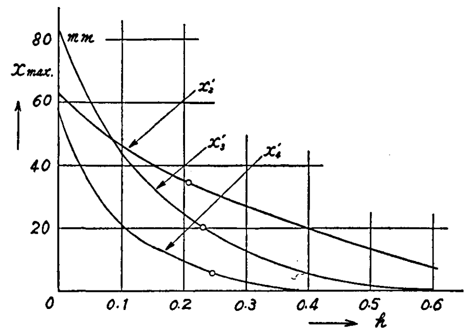

Fig. 6. The case of $x_1'=107$ mm, $t_1=0.418$ sec, $T_2'=0.99$ sec, $T_3'=1.31$ sec, $T_4'=0.90$ sec. ○: Observed values of x_2', x_3' and x_4' respectively.

factor has a tendency to increase slightly in accordance with a decrease in the amplitude (with natural period too for this case), but such trend is extremely small in comparison with a change in the amplitude ratio obtained by observation. These facts may tell that it is not a damping factor that changes by itself but it does not change by a change in the period, i.e., restoring force.

Figs. 7 & 8 show the relationship between period and amplitude under the free vibration, + side represents the periods T_1', T_3', T_5' corresponding to the amplitudes $i=1$, 3, 5, namly, x_1', x_3', x_5' and − side stands for the period T_2', T_4', T_6' corresponding to the amplitude $i=2$, 4, 6, namely x_2', x_4' and x_6', T_1' on the figure was calculated from t_1 at $h-0.2$.

The amplitude-period relationship is of similar trend on both sides of + and − and the natural period shows sharp increase up to certain value of the amplitude but it shows downward trend thereafter. The natural period is greatly affected by the initial deformation (load magnitude) and shows different values even under the same amplitude, details of which, however, will be reported at a later date.

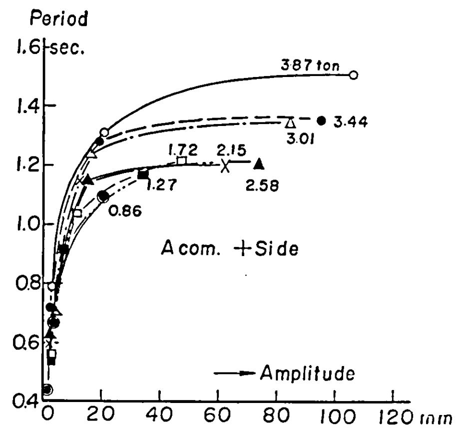

Fig. 7. Relation between displacement amplitude and free vibration period.

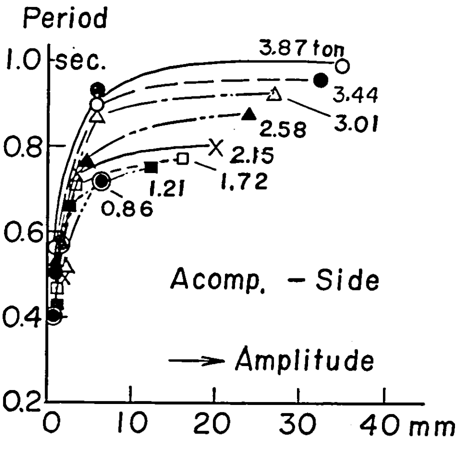

Fig. 8. Relation between displacement amplitude and free vibration period.

4. Conclusion

In this paper, a free vibration of a pendulum of simple mass system was considered, in which the restoring force varies at each amplitude and the relationships among amplitude, period & damping factor were theoretically derived and finally numerical calculations were made introducing the experimental data obtained for the free vibration of wooden house under great amplitude.

The comparison of the results and those from the actual measurements reveals that both values coincide at values of damping factor ranging $h=0.20\sim0.26$, showing a trend of slight increase with a decrease in either amplitude or period and further the fact that the amplitude ratio obtained from the measurements sharply varies at every amplitude may mean that a damping factor would change by change in the period, i.e., restoring force rather than it changes by itself. Then, T_1' was calculated from t_1 under $h=0.20$, which in turn enabled to obtain the relationship between amplitude & period of observed data, the results are that the natural period assumes different values even under the same amplitude according to the value of the initial deformation and it increases from 0.4 sec. to 1.5 sec. as the amplitude increases from 0.2 mm to 107 mm.

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19. 木造家屋の耐震性（第 3 報）

地震研究所 {西村源六郎
鈴木正治

構造物の振動実験には種々の条件によつて振巾に制限をうける場合が多い．現在まで多くの人々によつて測定された構造物の固有周期，減衰係数等の測定値の大部分は微小振巾による測定結果であるので大振巾時における振動特性との関連をつけておく必要がある．

この研究では，まづ単一質量系の振子の復元力が，各振巾毎に変化するような自由振動を考え，振巾，周期および減衰係数の関係を理論的に求め，大振巾で行なつた木造家屋の自由振動の実験の測定値を使つて数値計算を行なつた．

つぎに，その結果（数値計算で求めた振巾）と実測振巾とを比較して見ると，減衰係数 h が 0.20～0.26 の範囲で両者が一致し，固有周期または振巾が減少すると，減衰係数の値は多少増加する傾向にあることがわかつた．

以上の事柄より，実測値から求めた振巾比が大振巾時に各振動毎に著しく変化するのは，減衰係数が変化するよりはむしろ各振巾毎に固有周期が変化すること，すなわち家屋の復元力が変化する影響が大きいと考えられる．

なお上記の理由から $h=0.20$ 付近が大振巾時の減衰係数として適当と考え，t_1 から $h=0.20$ として T_1' を求め，この値と実測値の振巾および周期からこれ等の関係を求めた．その結果固有周期は大振巾時においては最初の変形により同一振巾でも著しくその値が異り，その値は，振巾値が 0.2 mm～107 mm に増加すると 0.40 sec～1.50 sec に増加することが認められた．
