8. *Horizontal Deformations of a Japanese Two-Storied Frame-House: (1) Vibration due to an Arbitrary Shock, (2) Vibration Caused by a Rotary with Unbalanced Mass, (3) Vibration due to Natural Wind, and (4) Deformation due to the Sun's Radiation Heat.*

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1. Introduction.

For the purpose of making a contribution to the study of a wind-proof construction of Japanese wooden-house, we measured the vibrations of a Japanese two-storied wooden house due to the pressure of natural wind. It is quite reasonable to do concurrently the measurement of natural wind by an anemometer installed at a position near the house of which the vibrations due to wind are measured. As a matter of fact, the vibration problem concerning the dynamical nature[1] of Japanese wooden-house caused by natural wind pressure remains to be treated, not to mention the concurrent observations of both the natural wind and the vibration of the house. The present paper contains not only the dis-

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1) Architects are aware that the problem of wind-proof construction of a wooden-house has been hitherto treated only as one of statics, while some of the experimental results of vibration measurement of a steel tower or re-inforced concrete building due to natural wind have already been obtained by some investigators.

F. OMORI, "Measurement of Vibration of the 660 Feet Wireless Telegraph Station Tower at Haranomachi," *Bull. Imp. Earthq. Investi. Comm.*, **9** (1921), 78-99.

F. OMORI, Engineering, **112** (1921), 196.

F. OMORI, "On the Vibration of Reinforced Concrete Chimneys", *Bull. Imp. Earthq. Investi. Comm.*, **9** (1918), 1-29.

T. SAITA, "Vibration of a Framed Structure House," *Rep. of the 14th Sub-Committee (Earthquake Proof Construction), Japan Committee for Promoting Science and Engineering, 1934.*

T. SAITA, "Earthquake Proof Properties of the Castle-Tower (Tenshukaku) of the Nagoya Castle," *Bull. Earthq. Res. Inst.*, **16**, (1941), 145-154.

cussions about the results of these concurrent observations,[2] but also the treatment of both the problem of the horizontal free vibrations due to an arbitrary shock and that of the horizontal forced vibrations excited by a rotary with unbalanced mass. In the last article of this paper, moreover, we studied a special problem concerning the natural horizontal deformation of a Japanese wooden-house due to thermal stresses caused by the radiation heat of the sun.

2. Measuring Apparatus for House Deformation.

The house treated by us is a kind of two-storied wooden house in

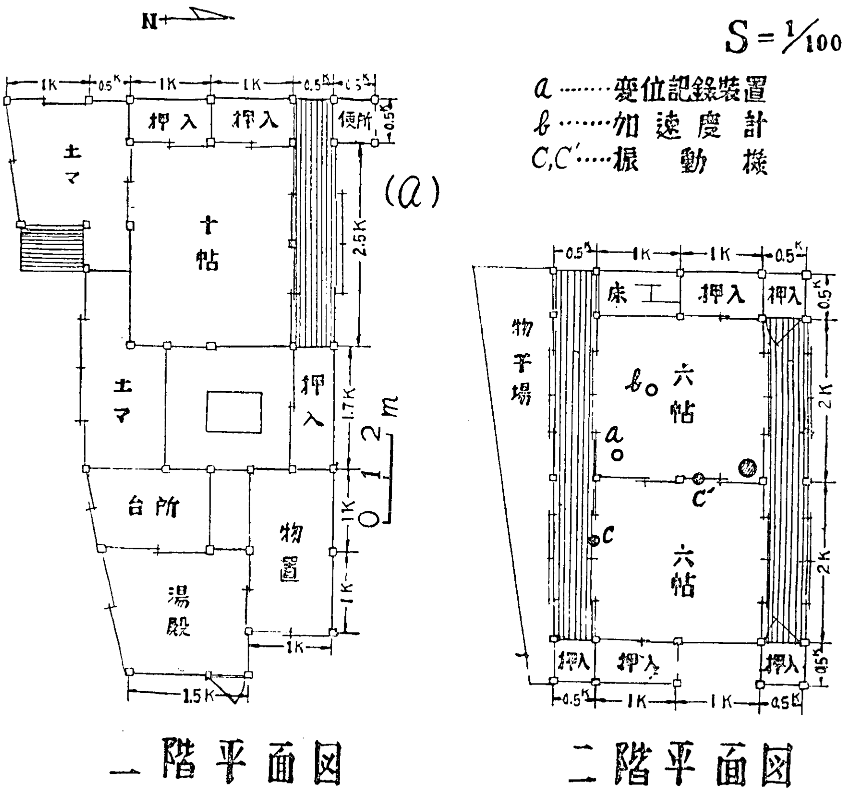

Fig. 1. Plan views of two-storied wooden house at 1st and 2nd floors.
(*a*): 1st floor, (*b*): 2nd floor.

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2) In the present study, the anemometer we used was the same with the one we used in the study of natural winds, which will be shown in the next but one Bull. Earthq. Res. Inst.

G. NISHIMURA and M. SUZUKI, "Anemometer of Inverted Pendulum Type and Wind Construction Studied with It," *Bull. Earthq. Res. Inst.*, **32** (1954), Part 3.

Japan, and the plan views of its 1st and 2nd floors are respectively shown in Fig. 1, the total area of the two floors being about 80 m^2. The respective heights of the two floors become about 0.5 m for the 1st floor and 2.0 m for the 2nd floor from the ground. The environment of the house is as follows. There are many Japanese one- or two-storied houses around the house, and on the east side of it there is an empty space of about 80 m^2, across which there is a one-storied work house at about one meter's distance from the house. On the west side, there is a small house of one story across a narrow street of about one meter's width, and a common Japanese wooden house of one-story is situated on the north side of the house. On the south side, there is a two-storied house at eight meters' distance from the house. The topographical map is shown in Fig. 2, and it contains the two stations

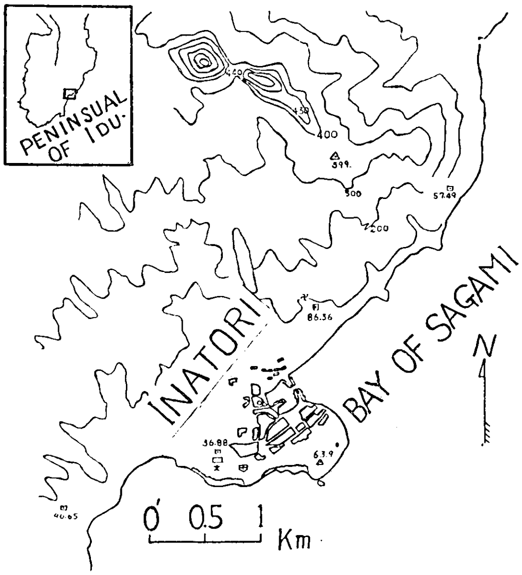


Fig. 2.

where the observations of natural wind and house vibration were carried out respectively and also their environment. The distance between the two observation stations should have been made as short as possible, but it turned out to be about 50 meters, for the reason that no other house was available for installing in it the measuring apparatus for house deformation as will be shown in this section.

For measuring the dynamical displacement of a house, it is generally convenient to use a displacement vibrograph when the vibration periods of it become comparatively short. As a matter of fact, however, the periods of house vibrations caused by natural winds, in some occasions, will become comparatively long, for the reason that the natural winds contain long periodic variations as may be seen in the characters of natural winds.[3] It is well known that a displacement vibrograph having a comparatively long period pendulum becomes generally unstable. For these reasons, the vibrograph of long period is not favourable for measuring the house vibrations caused by natural wind. Hereupon, if we want to use a short period vibrograph such as an acceleration- or a velocity-vibrograph, we are obliged to do some tedious works of integration and other treatments for obtaining the house displacement-vibrations due to natural wind. The two vibrographic methods mentioned above, in brief, become naturally unfavourable for the present study. From a new standpoint, therefore, clearing the vibrographic method, we obtained an apparatus for measuring the house vibrations excited by natural wind, of which the principle of measurement is very simple and primitive as will be shown. Assuming a long pipe uninfluenced by natural winds, the motions of the respective floors of the house due to natural wind will be measured relatively to this pipe; the pipe becomes comparable in height with that of the house to be under measurement, and one end of it is rigidly fixed in the ground. From the dynamical point of view, of course, the transversal vibration periods of the pipe must be as short as possible, and moreover shorter than the effective vibration periods of the house due to natural winds. Upon this principle, we constructed a measuring apparatus for house deformation as shown in Fig. 3a. Because the height of the ceiling of the house under measurement is about 5.5 m, we take 6.5 m as the total length of the pipe of the present apparatus. The upper part of the pipe is composed of aluminium pipe of 3.5 m in length, and the lower part of it is of steel pipe of 3.0 m in length, and they are connected by screw and flange at their connection point. The outer and inner diameters of the aluminium pipe are respectively 50 mm and 40 mm, and also the respective outer and inner diameters of the steel pipe become 90 mm and 80 mm. The lower part of the steel pipe just 0.5 m in length is concreted in the ground as shown in Fig. 3. The pipe is set, of course, through the 1st, 2nd floors and the ceiling of the house. To prevent contact between the pipe and any element of the house,

3) *loc. cit.*

there are empty spaces of a few centimeters between the pipe and the floors and also between the pipe and the ceiling of the house as may be seen in Fig. 3a. To cut off the effect of the wind, the pipe is tightly covered with a suitable box such as wooden-made long pipe of square section of which the area is larger than that of the steel pipe.

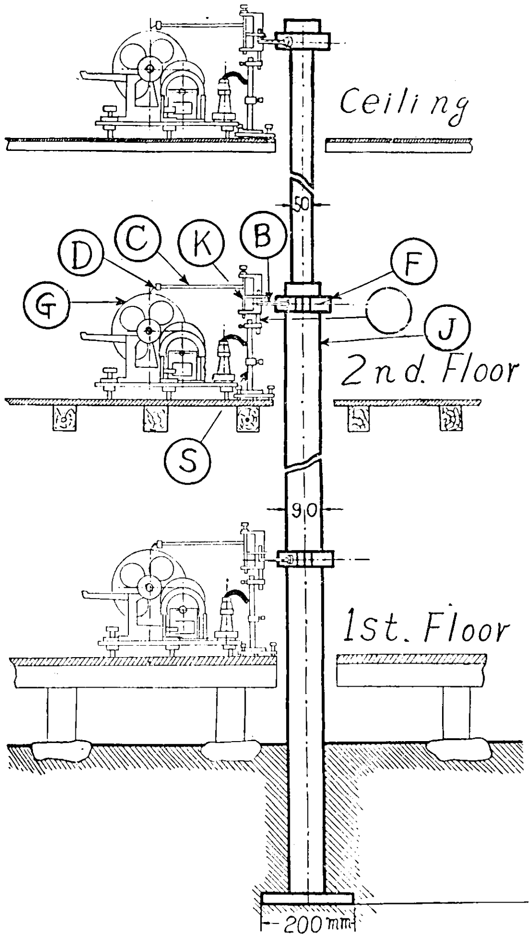


Fig. 3a. Measuring apparatus for house deformation.

Both the magnifying and recording methods for the present measurement are mechanical ones as in the case of the anemometer[4] which will be described in the next paper, and moreover they are exactly common

4) *loc. cit.*

to the three measuring points (1st floor, 2nd floor and ceiling). We will, therefore, explain them concerning the 2nd floor, and their sketch-maps are shown in Figs. 3a and 3b. Two steel rods (diameter 2 mm, length 5 mm) B are screwed normally into flange F which becomes concentric with the pipe J, and they become perpendicular with each other. The flange F is fixed by bolts and nuts to the pipe J at a desirable position in which each axial directions of the two rods become coincident with N-S and E-W directions[5] respectively. The curved end of the rod B is put into fork H of which the center rod K is pivoted by a suitable arm. Rod B makes a point contact with one of the two slightly magnetized arms of the fork H, and the arm pivoting the center rod K is put vertically on the 2nd floor by a suitable stand S as shown in Fig. 3a. The end of the recording stem C screwed into the center rod K has the recording needle D, which moves in accordance with the house-motion and records the two components of the house displacements on the smoked recording paper running with drum G. The recording drum G runs with suitable rotation speeds which are given by a phonic motor with gear mechanism.

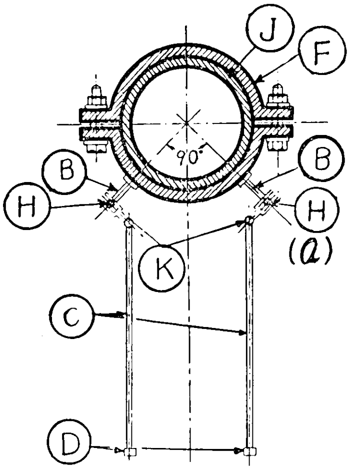


Fig. 3b. Measuring apparatus for house deformation.

For the present measuring apparatus, the mechanical magnification V of house-displacement on the 2nd floor is given by the following expression :

$$V=L/I,$$

where L expresses the length of recording stem C with recording needle D, and I the distance between the rotation axis of the center rod K and the point of the fork H with which the steel rod B contacts, and the value V becomes $10\sim13.3$ for the present apparatus. The running speed of the record-paper (=peripherial speed of the recording drum) assumes three kinds values i.e. 2.09, 0.174 and 0.0145 mm/sec for the present experiment.

5) The directions of the girder and the beam of the house under measurement become respectively N-S and E-W.

3. Free Vibration of the House.

The records of horizontal free vibrations of the house due to an arbitrary shock applied to a pillar on the second floor are shown in Fig. 4. These records have been of course obtained by the apparatus

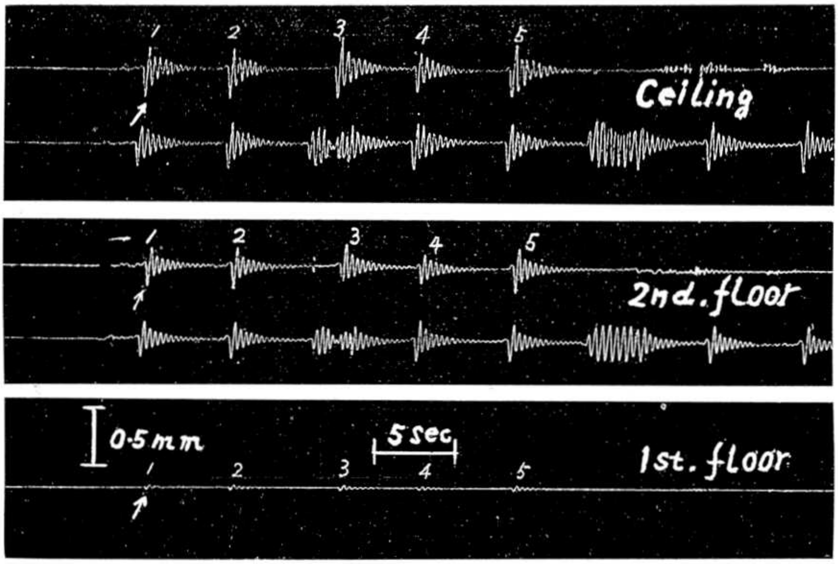


Fig. 4. Records of free vibration of the house.

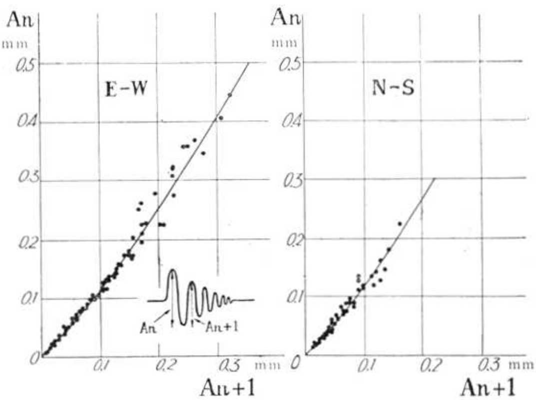


Fig. 5. Damping characters of E-W, N-S component free vibrations on the 2nd floor.

explained in the above section, and they show that the respective two components of vibration at the three places (1st floor, 2nd floor and ceiling) are in the same phase, and that they have the same value of the free vibration period in the same time.

(1) *Damping Ratio and Amplitudes.* Taking the n-th double amplitude A_n and next $(n+1)$-th double amplitude A_{n+1} in the free vibration record of the 2nd floor, we obtain Fig. 5, which shows the damping characters of the respective E-W, N-S component vibrations on the second floor of the house. From Fig. 5, we can see that the value of A_n/A_{n+1} or the damping ratio increases with the vibration amplitude. Expressing the relation between A_n and A_{n+1} as follows:

$$A_n = a(A_{n+1})^m , \qquad (1)$$

we obtain the values a and m as in the following Table I.

Table I. Values of a and m for the 2nd Floor.

Components	E-W	N-S
a	1.10	1.14
m	1.13	1.20

Now, from Table II which shows the relations between the amplitude A_n and the damping ratio v for both E-W and N-S components, we find the following facts: The damping ratio increases with the

Table II. Amplitude and Damping Ratio v on the 2nd Floor.

A_n (in mm)	v (E-W component)	v (N-S component)
0.05	1.06	1.08
0.10	1.10	1.17
0.20	1.25	1.27
0.40	1.35	

amplitude; when the amplitude becomes 4 multiples of small amplitude (0.05 mm), the damping ratio increases by about 18% of the damping ratio for the case of the small amplitude (0.05 mm). When they become 8 multiples of the small amplitude (0.05 mm), the damping ratio increases by about 28% of that for the case of small amplitude.

(2) *Period and Amplitude of Free Vibration.* As regards Japanese wooden house, from the observation results of the house vibrations,

T. SAITA[6] and one of the present writers have already explained that its free vibration period becomes longer as the vibration amplitude becomes larger. For the present study, we obtained generally the same results about the relation between the periods and amplitudes of the free vibrations of the house. On the present free damped vibrations as shown in Fig. 4, for large amplitude of vibration, we will take the first five continued vibrational motions from the beginning point of vibrational motion, and also for small amplitude, we will take the last five continued vibrational motions from the end point of free vibration. Taking the mean values of the periods of the respective first and last five free vibrations on the 2nd floor, we obtained the relation between the periods and amplitudes as shown in Table III.

Table III. Free Vibration Period and Amplitude on the 2nd Floor.

No. of experiment	E-W component				N-S component				Reference
	Front part of vibration		Rear part of vibration		Front part of vibration		Rear part of vibration		
	amplitude (mm)	period (sec)	amplitude (mm)	period (sec)	amplitude (mm)	period (sec)	amplitude (mm)	period (sec)	
1	0.43～0.08	0.335	>0.02	0.306	0.22～0.022	0.307	>0.01	0.288	error of calculated vibration period becomes less than 3%.
2	0.47～0.09	0.335	>0.02	0.314	0.25～0.03	0.287	>0.01	0.286	
3	0.42～0.08	0.345	>0.02	0.306	0.23～0.03	0.307	>0.01	0.288	
mean values	0.26	0.338	>0.02	0.308	0.13	0.304	>0.01	0.287	

From Table III, we find that the free vibration period of small amplitude (rear part of free vibration) of E-W component becomes longer by just 7% than that of N-S component. We can see, moreover, that for the two cases in which the respective ranges of the vibration amplitudes for E-W and N-S components become 0.45～0.08 mm and 0.23～0.02 mm, the free vibration periods increase to be about 10% longer than that of small amplitude less than 0.02 mm for E-W component and also to be about 6% longer than that of small amplitude less than 0.02 mm for N-S component respectively.

6) T. SAITA and M. SUZUKI, *loc. cit.*

(3) *Free Vibration Modes.* The free vibration modes of the house are shown in Fig. 6, which is obtained from the observation records of free vibrations at the three points (1st floor, 2nd floor and ceiling) of the

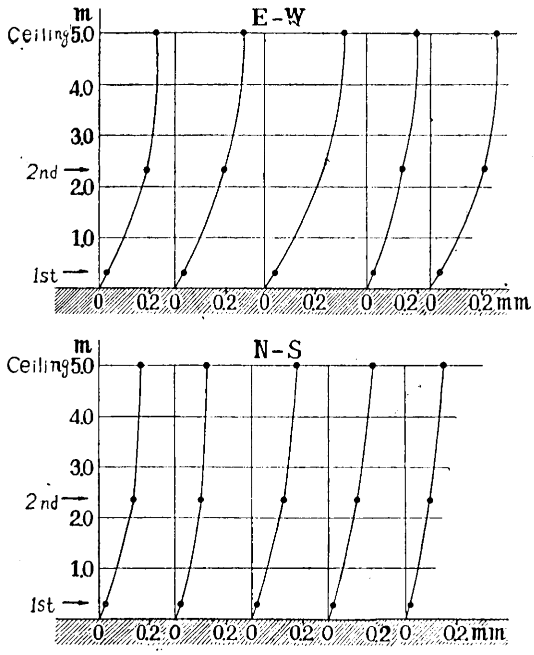


Fig. 6. Free vibration modes.

house, and Fig. 6 shows that the free vibration becomes the modes of shear vibration type. It is natural that the free vibration mode should become similar to the mode at the resonance condition of the forced vibration of the house caused by a rotary with unbalanced mass which shall be discussed in the next section.

4. Forced Vibration Caused by a Rotary with Unbalanced Mass.

To obtain the forced vibration of the house, we used SAITA's rotary[7] which is shown in Fig. 7. This rotary is mainly constructed with the rear hub and rim of a bicycle, and it is hand-driven by means of handle, chain and gear mechanism. To increase the rotation inertia of the machine, we put into the hub a lead wheel band instead of tire and tube. The unbalanced masses of 4 kinds shown in Table IV

7) T. SAITA, *loc. cit.*

are composed of lead wheel segments and they are rigidly fixed on the hub of radius 22.9 cm by bolts and nuts as shown in Fig. 7. When these four unbalanced masses are used, the hub will rotate uniformly

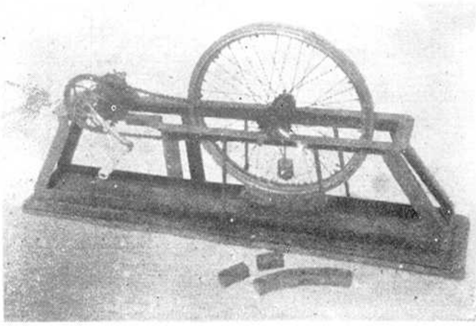


Fig. 7. Rotary with unbalanced mass.

for the range of rotation 7～1.5 R.P.S. Of course, in the working state of the machine, it must be kept off from any displacement with rattle on the floor for the purpose of obtaining reliable records of damped forced-vibrations of the house. By hand, the hub is put into a running state with the highest possible peripherial speed, and then into a free state of damped rotation.[8)]

Now we can easily obtain the following expression of the horizontal force caused by the machine which works horizontally to the house :

$$F=\frac{v^2}{r}M\cos\theta=4\pi^2\frac{r}{T^2}M\cos\theta\,, \qquad (2)$$

where F (in dyne) : Horizontal force caused by the machine,
r (in cm) : Distance between the center of mass of the unbalanced mass fixed to hub and the axis of the rotation of the wheel,
T (in sec.) : Rotation period of the wheel,
M (in gr.) : Mass of unbalanced mass,
θ (in degree) : Angle between the horizontal line and the line running through the two points, one being the center of mass of the unbalanced mass and the other center of the wheel in its running condition.

Now, using the unit of kg-wt for M, we obtain the following expression of F in kg-wt :

8) In the present experiment, we put this machine on the respective positions C and C' of the 2nd floor of the house, which are shown in Fig. 1b.

$$F=0.923\,MT^{-2}. \qquad (3)$$

In Table IV, the maximum horizontal force for $T=1$ sec. is shown for respective unbalanced masses.

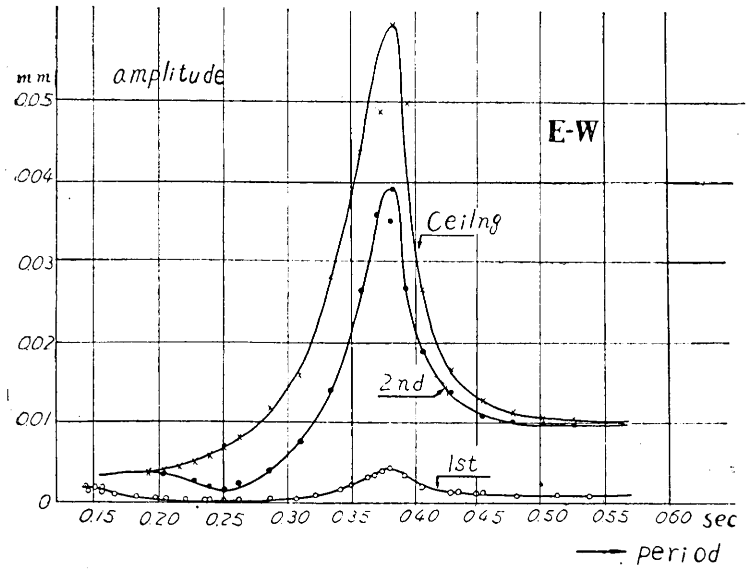
Table IV. Weights of Unbalanced Masses and Max. Horizontal Forces due to Them.

Kind of unbalanced mass	*Ma*	*Mb*	*Mc*	*Md*
Wt. of unbalanced mass (in Kg.)	1.00	1.70	3.40	5.10
Max. horizontal force (in Kg-wt)	0.92	1.57	3.14	4.71

For the case of free damped rotation of the rotary with unbalanced mass $M_c=3.4$ kg, we obtained the records of the forced vibrations of the respective three places (1st and 2nd floors, ceiling) as shown in Fig. 8. In this case, moreover, the record of acceleration vibrograph[9] is also shown in Fig. 8. The displacement calculated from this record becomes, of course, equal to the displacement obtained directly from the present displacement measurement apparatus.

According to the damping degree of revolution of the unbalanced mass rotary, the resonance amplitude of vibration becomes of course somewhat different, but this fact has no serious effect on the certification of the resonance period of the house. As the maximum horizontal force applied to the house by the machine becomes proportional to the square of T, we are able to calculate the maximum vibration amplitude for the constant maximum force of the respective periods. The amplitude obtained by the product of T^2 and the maximum amplitude of the respective periods becomes equal to that of the respective periods corresponding to the maximum force 0.923 M (kg-wt). From these treatment, we obtained the relations between the displacement amplitude and the period for the three respective locations (1st floor, 2nd floor, ceiling) when the maximum horizontal force becomes 3.14 kg-wt as shown in Fig. 9. From these curves in Fig. 9, we can see that for N-S component, the displacement commonly reaches its maximum when the period becomes 0.34 sec. for all three locations, and also for E-W component, it reaches its maximum when the period be-

9) The accerelation vibrograph used is ISHIMOTO's seismograph of which natural period=0.115 sec., sensibility=2.0 gal/mm, mechanical magnification=213, weight of mass=13 kg, damper=air damper, and recording method=mechanical smoked paper one. It is installed at *b* location on the 2nd floor of the house shown in Fig. 2.



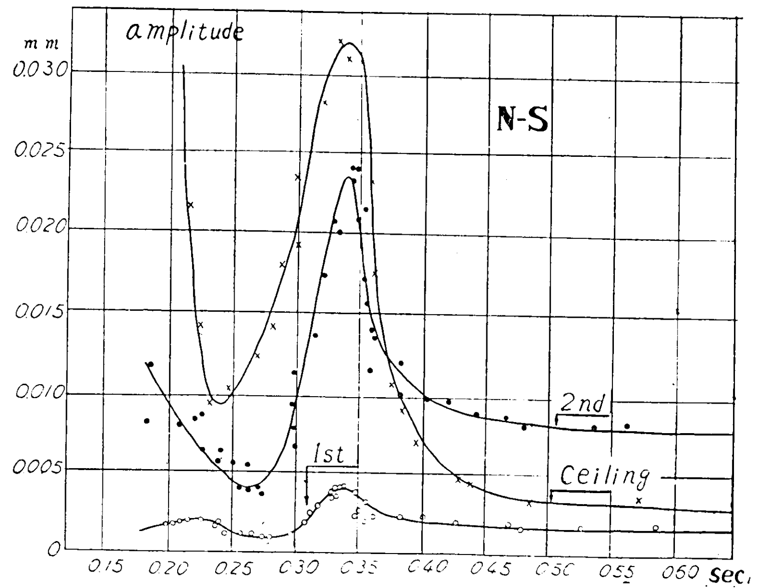


Fig. 9. Relations between displacement amplitude and period.

comes 0.38 sec. When the period of applied force becomes longer than 0.55 sec., the respective displacements for E-W and N-S components become roughly constant, and this fact shows that the problem turns into a statical one when the period surpasses 0.55 sec. Table V shows both the N-S and E-W component displacement-amplitudes of the three locations when the statical displacement of E-W component on the 2nd floor is taken to be unit.

Table V. Displacements When Statical Displacement of E-W Component on 2nd Floor is Taken to be Unit.

Position / State / Component	Ceiling		2nd Floor		1st Floor	
	statical state	resonance state	statical state	resonance state	statical state	resonance state
E-W	1.06	6.2	1.0	4.55	0.10	0.46
N-S	0.334	3.33	0.82	2.27	0.167	0.41
ratio of N-S and E-W components	0.334	0.536	0.82	0.50	1.51	0.89

This table reveals the following facts; excepting the statical state of the 1st floor, for both statical and resonance states the amplitudes of N-S component become generally smaller than that of E-W component for all two floors and ceiling, and they become smallest at ceiling, and

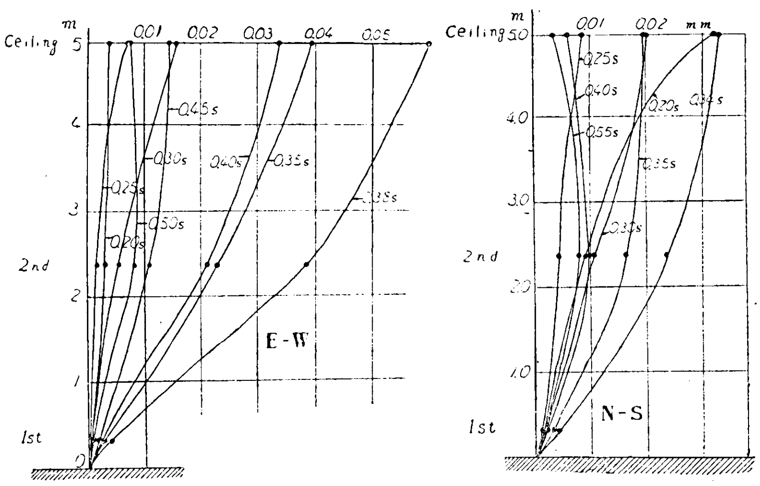


Fig. 10. Forced vibration modes.

also the ratios of N-S component and E-W component for both statical and resonance states for the upper floor have smaller values than that for the lower floor of the house. These two facts show that both the effective statical-and dynamical-strength for N-S component of the house becomes larger than that for E-W component, and also the upper part of the house becomes effectively stronger than the lower part of it.

The vibration modes of the house for both E-W and N-S components are shown respectively in Fig. 10, in which the parameter of the curves is taken as time in sec. In Fig. 10, we can see that both the vibration modes for N-S and E-W components for resonance condition become

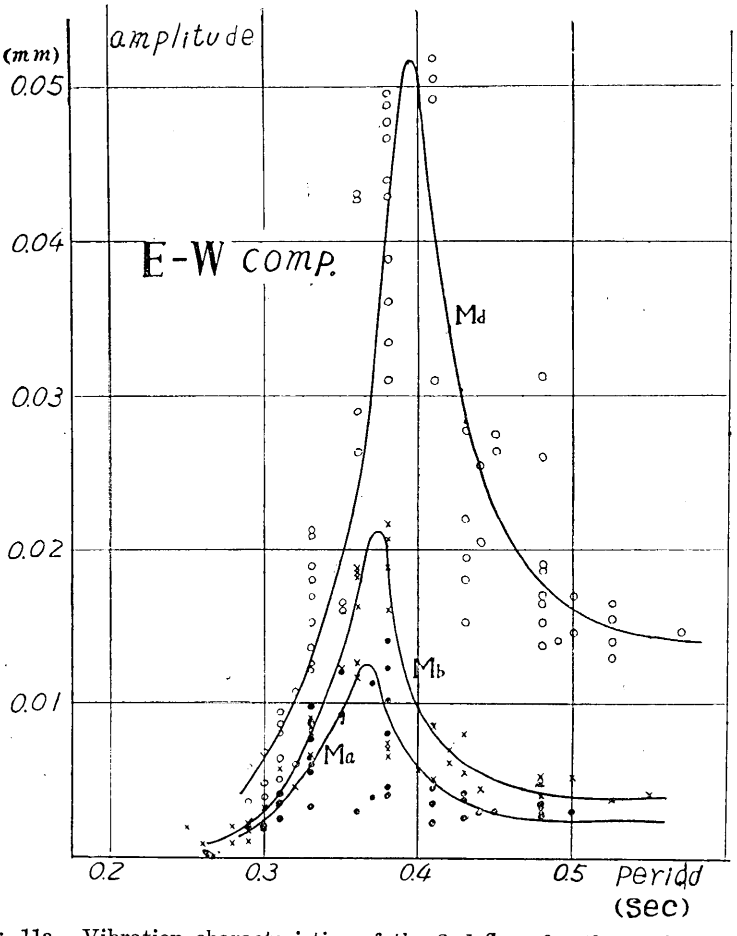


Fig. 11a. Vibration characteristics of the 2nd floor for the variation of unbalanced mass of the rotary.

naturally similar to that of the free vibration mode of the house which is already shown in Fig. 6. When the period of the applied horizontal force becomes long, the amplitude of both the 2nd floor and ceiling become nearly equal, but in the case of more longer periods the amplitude of the 2nd floor becomes somewhat larger than that of the ceiling. This tendency appears especially more distinctly for N-S component than for E-W component. The reason why the displacement of the 2nd floor becomes distinctly large, is that the horizontal force caused by the rotary is applied on the 2nd floor and also the 2nd floor is of rather weak construction. When the period of the applied force becomes

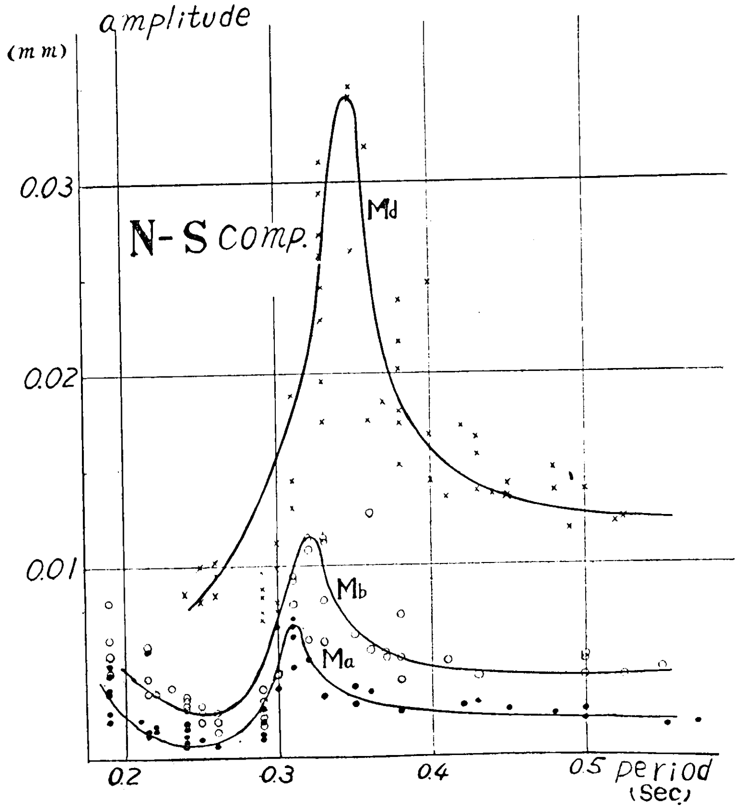


Fig. 11b. Vibration characteristics of the 2nd floor for the variation of unbalanced mass of the rotary.

shorter than the resonance period of the house, the respective three locations (1st floor, 2nd floor and ceiling) show their respective different vibrations and also seem to have their own respective resonance periods. This fact shows that the house cannot vibrate wholly as a single body, and that the three locations vibrate with their respective vibration modes for the reason of the dynamically weak construction.

Now the vibration characteristics of the 2nd floor for the variation of unbalanced mass of the rotary on the 2nd floor are shown in Fig. 11 for E-W and N-S components respectively. In E-W component (Fig. 11a), observed points marked with ●, ×, ○ correspond to the unbalanced masses M_a, M_b and M_d respectively, and also the points marked with ●, ○, × in N-S component (Fig. 11b) shows respective cases of M_a, M_b and M_d. The vibration characteristics for the case of M_c are already shown in Fig. 9. The curves in Fig. 11 correspond of course to the maximum horizontal forces shown Table IV. From Fig. 11, we can see that the resonance period on the 2nd floor slightly varies as the unbalanced mass varys and that it shows a tendency to be elongated as the maximum force becomes larger. And this tendency appears more distinctly in the N-S component than in the E-W component. This fact shows that the dynamical construction of the N-S direction of the house may be weaker than that of the E-W component.

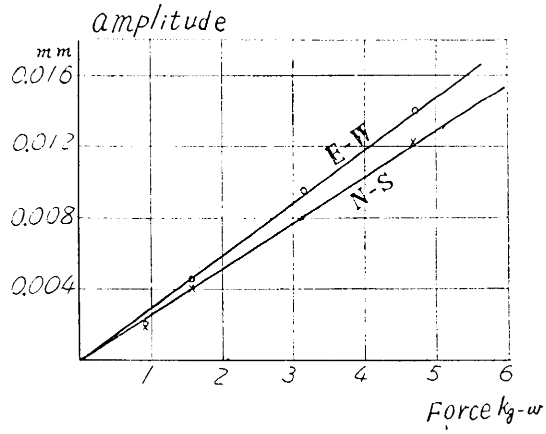


Fig. 12. Relation between the applied statical force and the maximum horizontal deflection of the 2nd floor.

From Figs. 9 and 11, we are able to obtain the relation between the force intensity applied horizontally to the house and the maximum horizontal displacements in both statical and dynamical states; Fig. 12 shows the relation between the statical force applied to the house and the maximum deflections of the house on the 2nd floor, the statical force of course being the force with the period longer than 0.55 sec. for the present house, and also Fig. 13 shows the relation between the dynamical maximum deflection of the 2nd floor at the resonance condition and the dynamical force of period 0.32 sec. applied to the house. Of course, the two curves in both Figs. 12 and 13 are cases of N-S and E-W components respectively. From Figs. 12 and 13, we can see

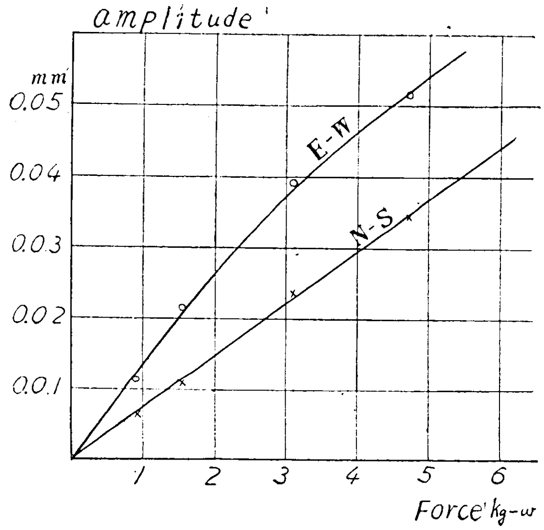


Fig. 13. Relation between applied dynamical force and maximum deflection at 2nd floor.

that the statical deflection of course becomes proportional to the applied force but the dynamical deflection does not become necessarily proportional to the intensity of applied horizontal force. As for the present house, the fact that the E-W component does not become proportional may be explained by the increase in the decaying factor worsening of the condition of the house with the increase in deflection caused by the applied force. Of course this property is mainly due to the construction of the house.

From Figs. 9 and 11, we obtain Fig. 14 which shows the variation of resonance displacement due to that of resonance period on the 2nd floor and in which the points marked with $\times$ correspond to the state of free vibration. We can understand from Fig. 14 that the resonance period of the house becomes much elongated by the finiteness of vibration amplitude, which is of course due to the intensity of the applied force. In Fig. 14, moreover, we can see that the free vibration period obtained from small vibration amplitude becomes much smaller than that obtained from forced large vibration amplitude. The resonance period corresponding to comparatively large forced vibration amplitude, moreover, becomes comparatively longer than that of the comparatively small forced vibration amplitude. From the discussions about Fig. 14, we obtain the important fact about the resonance phenomenon of wooden

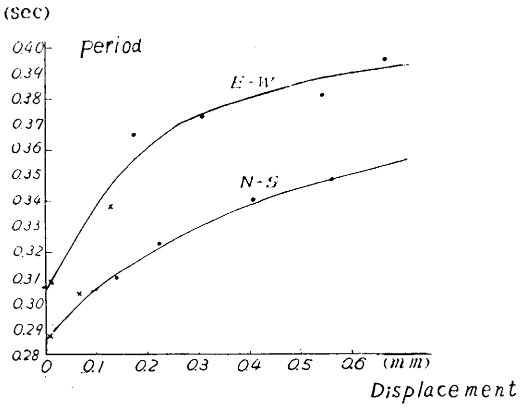


Fig. 14. Relation between displacement amplitude and resonance period.

house as follows: When the resonance period of a wooden house is discussed, it must be stated whether the vibration condition is a free or a forced one and moreover whether the vibration amplitude becomes infinitesimal or finite.

5. Vibrations due to Pressure of Natural Winds.

In the present section, we shall discuss the results of the concurrent observations of both the natural winds and the house vibrations caused by them. The apparatus used for this concurrent observations has already been introduced in the preceding section. As the method of analysis of the wind pressure will be shown in the next paper[10] in which we shall discuss the wind construction, we do not show it in this paper. In this section, we shall first discuss the relation between the wind pressure and the house displacement and next we shall study the statistical characters of the vibration periods of the house due to wind and the predominant period. The problems concerning the relation between the periods and the amplitudes of the house vibrations caused

10) *loc. cit.*

by natural wind and also the nature of the deformation vectors of the house due to natural wind will be studied in this section.

(1) *Wind Pressure and Displacement of the House.* Now we will take the following two cases of observation of winds: (1) S-E wind blowing for the space of 8 hours and 45 minutes from 22^h, Sept. 11 to 6^h45^m, Sept. 12, 1941, in which the maximum wind speed reached 23 m/s, and also (2) N-W wind lasting for the space of 23 hours and 12 minutes from 18^h48^m, Sept. 16 to 18^h, Sept. 17, 1941, in which the maximum wind speed reached 35 m/s.

Using the respective records of both wind pressures and the house vibrations, we calculated the mean values of the wind pressures of NE-SW direction and those of SE-NW direction, and also the mean values of the vibration amplitudes of E-W component and those of N-S component. By these procedures, we obtained the relations between

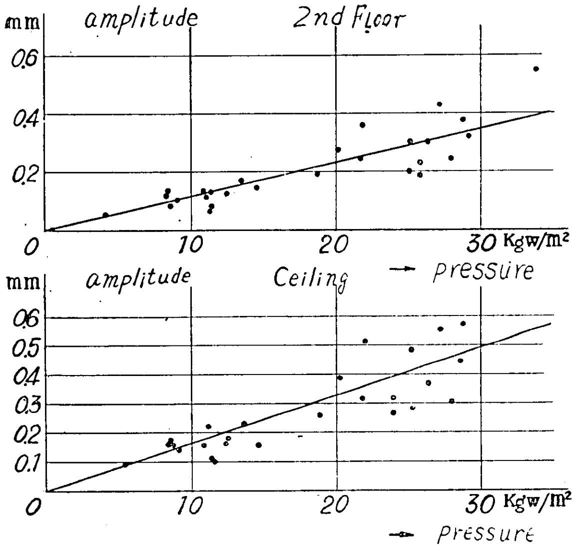


Fig. 15. Relation between wind pressure and house displacement amplitude S-W wind.

the wind pressure and the vibration amplitude of the house on the ceiling and on the 2nd floor as shown in Figs. 15 and 16. From Figs. 15 and 16, we can see that the vibration amplitudes become roughly proportional to the maximum wind pressure for both winds (S-E wind, and N-E wind). From the theoretical point of view, this character of proportionality may be of course right, but actually the respective points marked with ● in Figs. 15 and 16 do not necessarily form a regular curve such as a straight line. This fact is of course due to the facts that both the house displacements and the wind pressures have respectively dynamical natures and also the two stations where the observation of the wind and house deformation are respectively carried out have a 40 meters' distance between them. Figs. 15 and 16

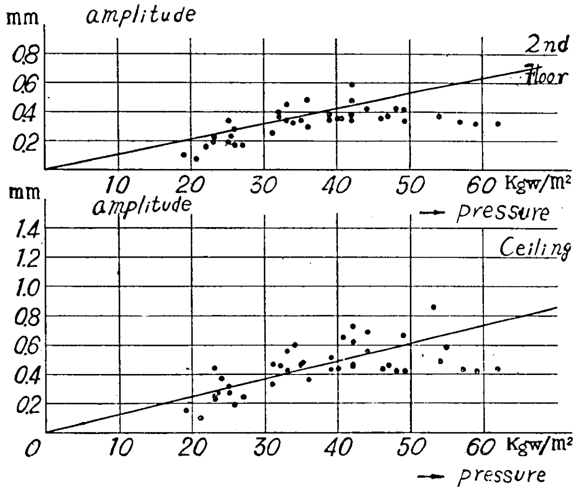


Fig. 16. Relation between wind pressure and house displacement amplitude S-W wind.

show that for the wind pressure of 30 Kg-wt/m², the two displacements on ceiling and 2nd floor become respectively 0.49 mm, 0.38 mm for S-E wind, and 0.37 mm, 0.30 mm for N-E wind. Hence we learn that the displacements on ceiling and 2nd floor due to S-E wind become larger than those due to N-W wind. We cannot, however, explain easily these facts from the theory that when the intensity of wind pressure is the same, the displacement of the house due to the wind is of the same magnitude even when the directions of the wind are diametrically opposite to each other. In the present case, as already mentioned, the two concurrent observation stations have a distance of 40 metres between them and both the environment of the houses and the topography around the house are not uniform. From these two facts, we are able to infer that the effect of N-W wind pressure on the house is more or less varied and weakened mainly by the environment of N-E side of the house.

(2) *Statistical Characters of the Vibration Periods of the House due to Wind and Their Predominant Period.* Taking two records of the house displacement which are respectively caused by N-E wind of the duration from 17^h35^m to 17^h55^m, March 2, 1941, and by S-W wind of the duration from 12^h17^m to 12^h27^m, March 4, 1941, we studied the statistical characters of the vibration period of the house. Figs. 17a and 18a show respectively the vibrations of the house for the above-mentioned two durations of time. Parts of the records of the wind pressure for these two time durations are also shown in Figs. 17b and 18b respectively. Figs. 19 and 20 show the statistical characters of the house vibrations of N-S component caused by N-E wind of which the duration of time (5 minutes) is taken arbitrarily from 17^h35^m to 17^h40^m and also from 17^h40^m to 17^h45^m respectively. In Figs. 19 and 20, the values of the

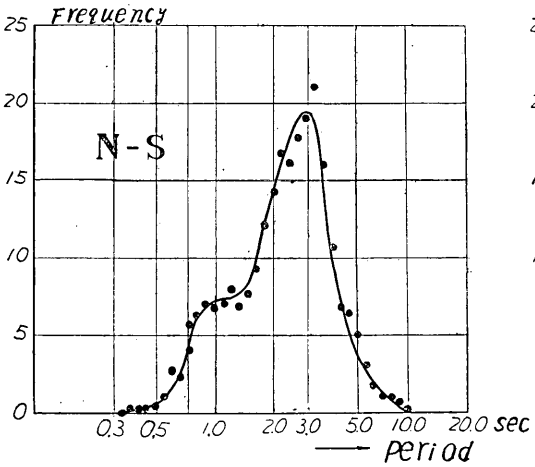


Fig. 19. Relation between vibration period of the house due to N-E wind and their predominant period. Observation time $=17^h35^m \sim 17^h40^m$, March 2, 1941.

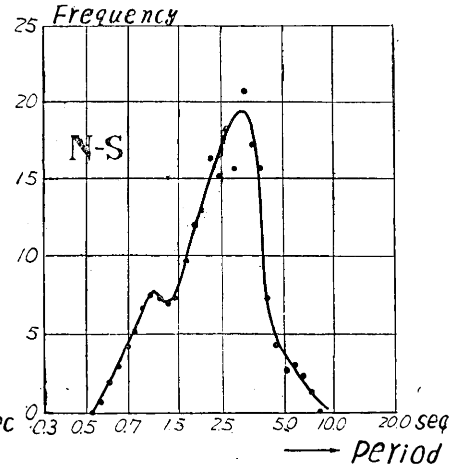


Fig. 20. Relation between vibration period of the house due to N-E wind and their predominant period. Observation time $=17^h40^m \sim 17^h45^m$, March 2, 1941.

period taken on the abscissa of log. scale are obtained by the method wherein we take, as the period of the house vibrations, the time duration from a top to the next top on the recorded curve of the vibration of the house in Figs. 17a and 18a, or the time duration from a bottom to the next bottom on the same records. The ordinates in Figs. 19 and 20 show also the total numbers of which we summarized the numbers of the same values of periods for the same duration of time

(5 minutes) as in Figs. 17a and 17b. The natures shown by the curves in Figs. 19 and 20 become approximately the same, and therefore we can say that the result is same whether the observation time of

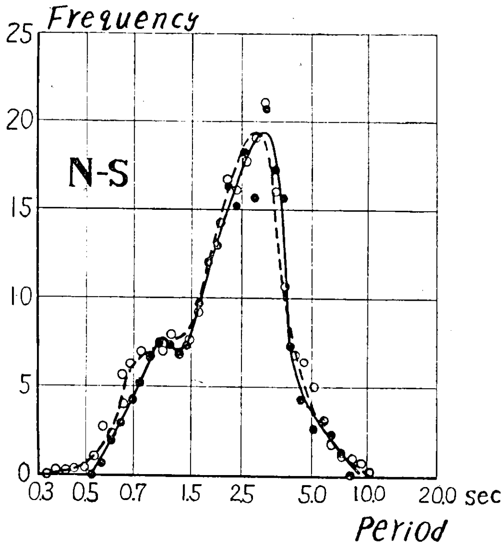


Fig. 21. Relation between vibration period of the house due to N-E wind and their predominant period.
○ 17^h35^m～17^h40^m March 2, 1941
● 17^h40^m～17^h45^m 〃 〃 〃

duration is 5 minutes or 10 minutes. From Figs. 19 and 20, or from Fig. 21 which shows the results obtained from 10 minutes observation, we learn that there are two maximum values of the vibration periods such as 1.0 sec., 3.0 sec. respectively. We shall call these values of period as the *predominant periods* of the house subject to winds. Fig. 22 shows the statistic characters of the house vibrations of the respective two components of E-W and N-S due to the same wind during the time from 17^h45^m to 17^h55^m. Fig. 22 shows that the predominant periods become 2.3 sec. for E-W component and also 2.7 sec. for N-S component respectively. In the same way, the predominant periods caused by the S-W wind become as follows: Fig. 23 shows the statistical results which are obtained from the observation time duration from 12^h17^m to 12^h27^m by the same statistical method as in the preceding case of N-E wind. From Fig. 23, we find that, for the predominant periods of the house for E-W vibration component, there are two values i.e. 0.6 sec.

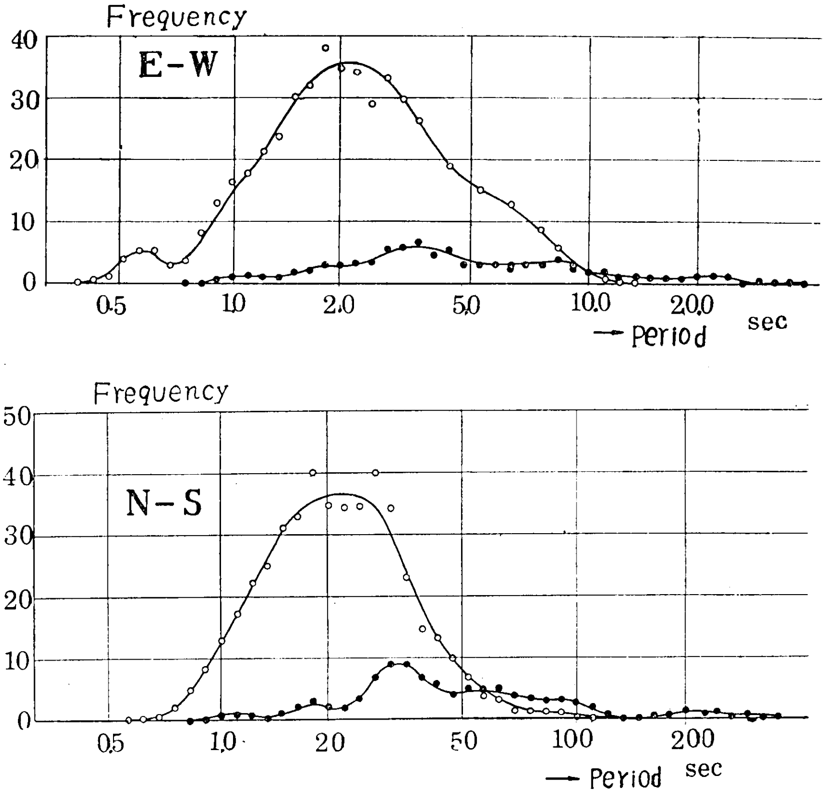


Fig. 22. Relation between vibration period of the house due to N-E wind and their predominant period. 17^h45^m to 17^h55^m March 2, 1941.

and 2.4 sec., but the predominant period for N-S direction becomes roughly 2.5 sec.

From the discussions about the predominant periods of the house vibration caused by the winds, of which the natures are shown in

Table VI. Predominant Periods of the House Vibration Caused by Natural Wind.

Wind Direction / Vibration Component	N-E Wind (sec.)		S-W Wind (sec.)	
N-S Direction	1.0	2.7, 3.0		2.5
E-W Direction		2.3	0.6	2.4

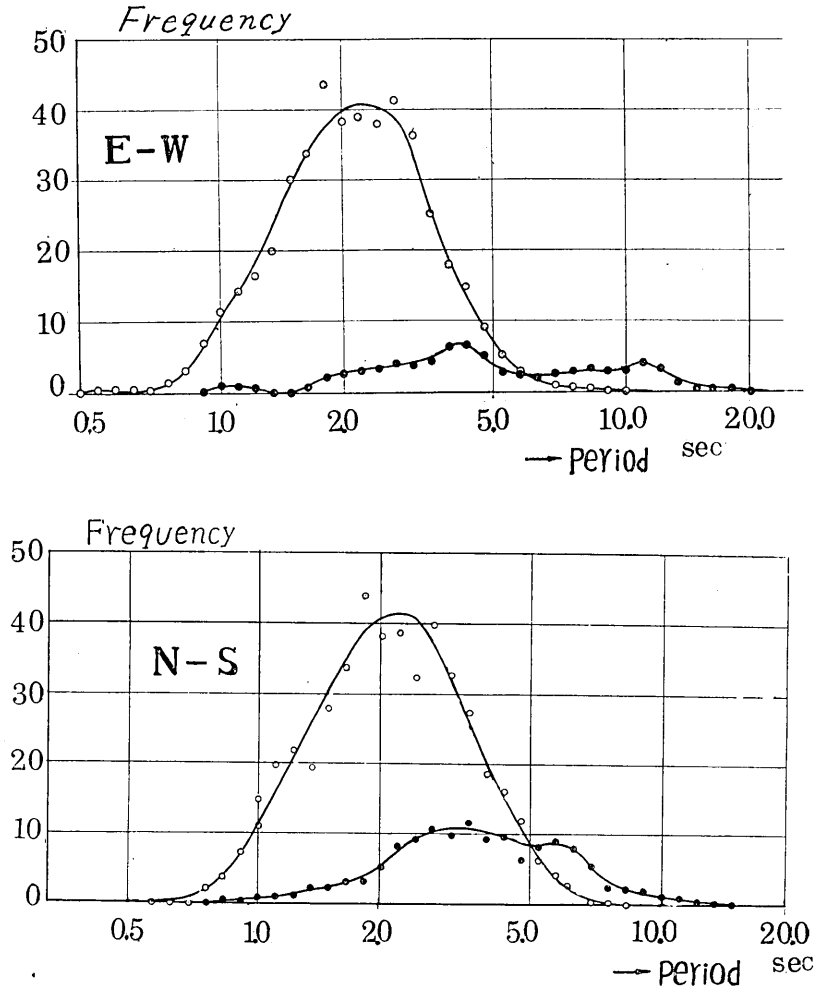


Fig. 23. Vibration period of the house due to S-W wind and their predominant period. 12^h17^m to 12^h27^m.

Figs. 26~32, we obtain Table VI in which the predominant periods are tabulated. The values of both the free vibration period and the resonance periods of this house shown in the preceding sections become of course shorter than that of the predominant periods shown in Table VI. From Table VI, we can say that the predominant periods of the house become generally longer than the proper periods of it such as free vibration periods or forced resonance periods. Now the vibrations with these predominant periods do not necessarily show the property of the displacement of vibration during the time of these predominant periods beginning from equilibrium position or zero displacement and returning again to the zero displacement. Regarding the displacements

Table VII. Predominant Duration Times.

Kind / Component	(A)	(B)	(C)
E-W	3.8∼12 sec.	3∼10 sec.	20 sec.
N-S	3.0∼6.0 sec.	3.5∼8.0 sec.	20 sec.

which begin from zero displacement and return again to zero, its duration time becomes generally longer than the predominant periods mentioned above. For example, we take the vibration records due to N-E wind

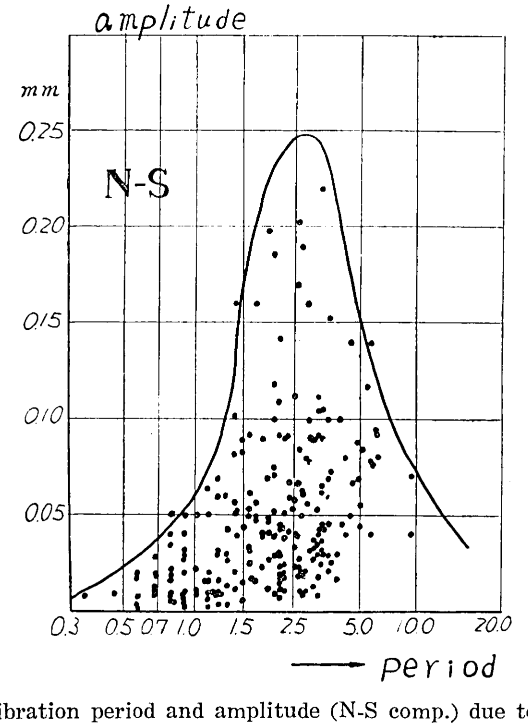


Fig. 24. Vibration period and amplitude (N-S comp.) due to E-N wind. Obs. Time$=17^h35\sim17^h40^m$.

during the 5 minutes from 17^h45^m to 17^h55^m and also the 10 minutes from 12^h17^m to 12^h27^m. Using these vibration records, we analyse the predominant duration times in which the displacement begins from zero position and again returns to zero position as shown in Table VII. In Table VII, (A) corresponds to the vibration record during the time from 17^h45^m to 17^h55^m, and also (B) corresponds to that during the time from 12^h17^m to 12^h27^m. In addition to the values corresponding to (A) and (B) shown in Table VII, from the above-mentioned vibration records

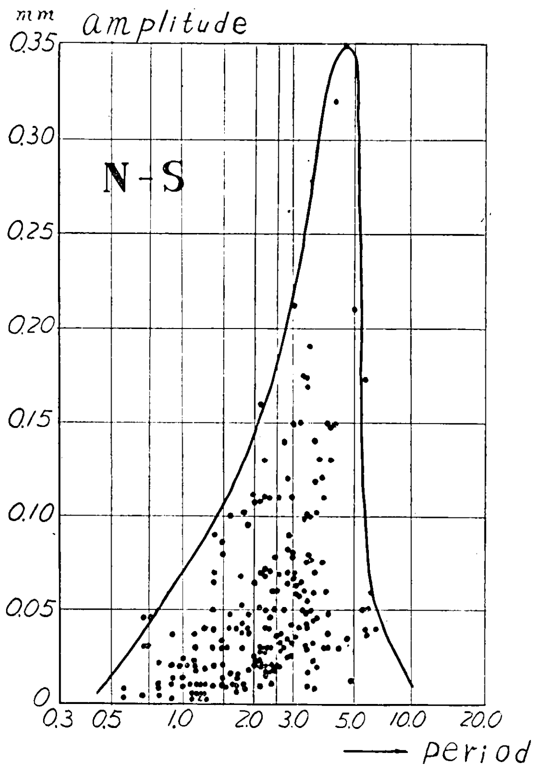


Fig. 25. Vibration period and amplitude (N-S comp.) due to E-N wind. Obs. Time$=11^h40^m \sim 17^h45^m$.

of both components N-S and E-W, we found the value 20 sec. to be the predominant period. And this value is shown in (C) kind in Table VII. Of course the free vibrations of the house must be generated by the wind, and the phases wherein the periods become 0.30∼0.32 sec., are predominantly found in the records of both E-W, N-S components of vibrations, but their amplitudes become very small compared with those of the above-mentioned phases, and become moreover only about 1/20 of the amplitude of the other predominant phase which we have already explained.

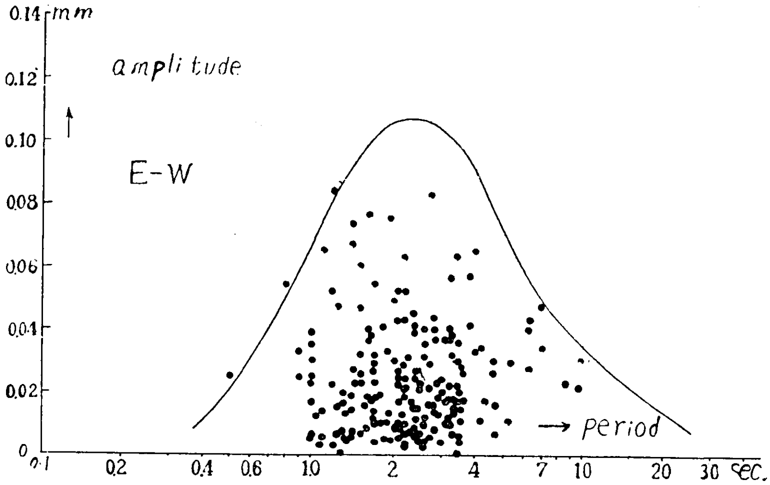


Fig. 26. Relation between vibration amplitudes and period due to S-W wind.

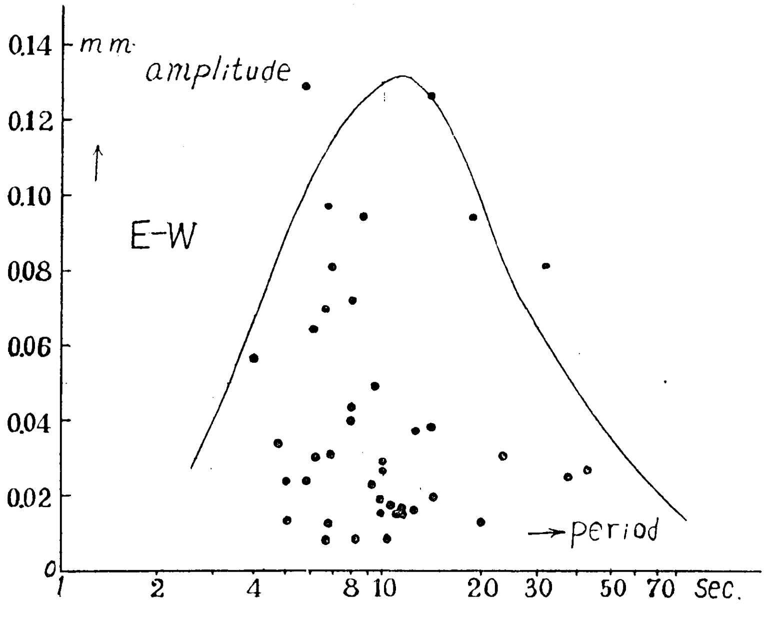


Fig. 27. Relation between vibration amplitude and period due to S-W wind.

(3) *Period and Amplitude.* Figs. 24 and 25 show respectively the relations between vibration amplitude and its period due to N-E wind during the 5 minutes time from 17^h35^m to 17^h40^m and also from 17^h40^m to 17^h45^m. From Figs. 24 and 25, we can see that the periods corresponding to the large amplitudes become about 3.1 sec. and 4.5 sec. respectively. Fig. 26 shows also the relation between the periods and amplitudes due to S-W wind during the 10 minutes time from 12^h17^m to 12^h27^m, from which we can see that the periods corresponding to large amplitudes become about 2.5 sec. Fig. 27 shows the relation between the time, in which the displacement begins from zero and also returns again to zero, and the maximum amplitude during this time. From Fig. 27, we can also see that the time corresponding to large amplitude becomes about 10 sec.

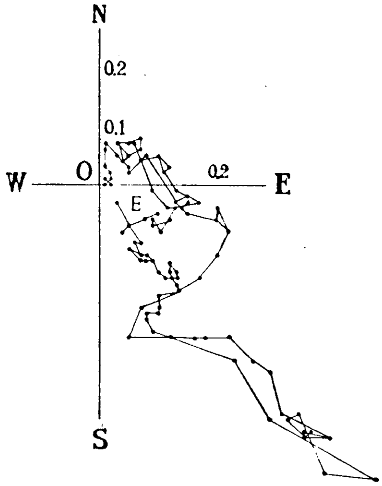


Fig. 28. Vector diagram of the house vibration due to the wind during about 60 sec. from $2^h45^m40^s$ on March 4, 1941.

(4) *Displacement Vectors.* Taking both E-W and N-S components of the records of the house vibrations caused by two winds, one of which is the wind (for about 60 sec.) from $2^h45^m40^s$ on March 4, 1941, and the other is the wind for about 50 sec. from 2^h45^m on March 4, 1941, we obtain the displacement vectors of the house vibration in every 0.48 sec. for both two vibrations which are shown in Figs. 28 and 29 respectively. Fig. 28 shows that the house generally moves in the direction of E-S during this time of 50 sec., and that it also returns to the same initial position passing through the same way during this wind blow of 50 sec. Fig. 29, however, shows that the house generally moves in a manner more complicated than the movement shown in Fig. 28, and that it moves through three quadrants during the wind blow of 60 sec. During two short neighbouring wind blows of S-W wind as in the present case, the motions of the house differ greatly as shown in Figs. 28 and 29. These two natures of the vibration of the house may of course be caused by the facts that the wind construction is very complicated, and that the natural wind varies greatly in its blowing directions even during tne short time of about 60 sec. These facts of the nature of the blow-

ing wind mentioned above shall be explained in the next paper[11], in which we will show the study of the wind construction by a short time observation of the blowing wind.

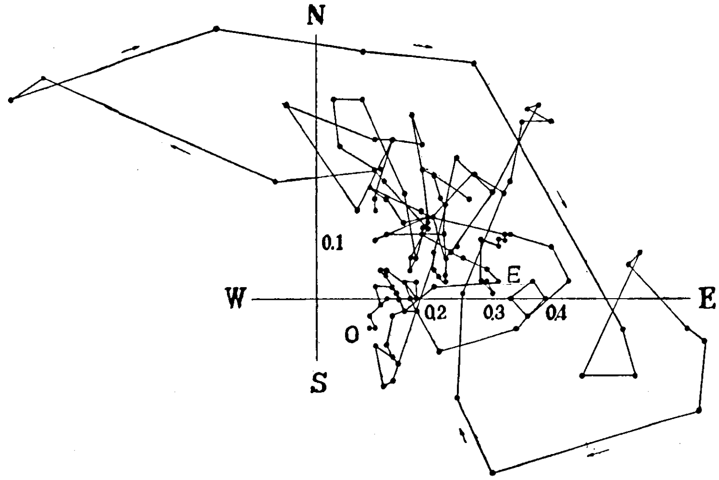


Fig. 29. Vector diagram of the house vibration due to the wind during about 50 sec. from $2^h45^m\ 0^s$ on March 4, 1941.

6. The Statical Displacement of the House due to the Sun's Radiation Heat.

It was very calm and there was no wind during the five days from 17^h, Sept. 10 to 17^h, Sept. 15, 1945. For the space of these five days, we obtained the records of the house displacement of both N-S, E-W components, and the parts of them are shown in Fig. 30, in which the upper three curves show respectively the E-W displacement components on the 1st flow, 2nd floor and ceiling, and the lower three curves correspond respectively to the N-S displacement components on the respective three places (1st floor, 2nd floor and ceiling). From Fig. 30, we can see that the two components of the respective three places have generally a common variation period of 24 h. The house begins to move in the E-S direction from 6 h morning and it returns again to the original position at about 6 h next morning, and moreover the two components of the three respective places have different residual permanent displacements respectively. The respective displacements on the 2nd floor and on the ceiling generally assume same phase with respect

11) *loc. cit.*

to both the E-W and the N-S components for the present house. The displacement magnitudes on the 1st floor become almost equal for both the E-W and the N-S components, but the displacement magnitudes of

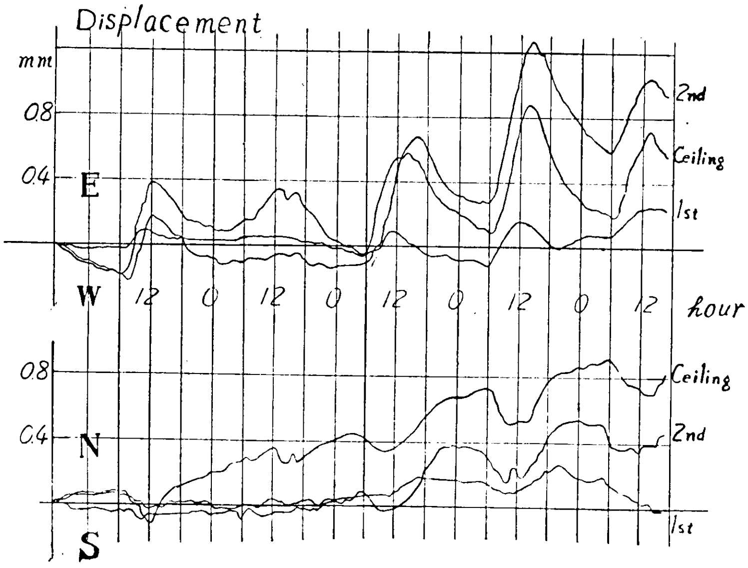


Fig. 30. Displacement of the house due to the sun's radiation heat.

the 2nd floor and ceiling on E-W component turn to be about three times of those on the S-N components shown in Fig. 39. The phase differences between the 1st and 2nd floors or between the 1st floor and ceiling become about 2 hours, and the phase of the maximum displacement on the 2nd floor has 2 hours time-lag compared with those on the 1st floor.

These phenomena concerning the deformation of the house become similar to the daily variation of the atmospheric temperature. When the daily variation of the atmospheric temperature becomes large as on a fine weather, the daily variation amplitude of the deformation of the house also becomes large, and it comes near zero when the weather is bad or rainy. These house deformations can be explained from the fact that the house is exposed to the radiation heat of the sun, and that its deformation is caused by the thermal stresses effectively induced into the house.

Using Fig. 30, we obtain Fig. 31 in which the vector diagram of the deformation of the house on the 2nd floor is shown. The numbers such as 6, 12, 18, 0 on the curve shows the time of a day in hour.

From the vector diagram in Fig. 31, we can see that the daily variation of the deformation becomes same and similar for every day, and the maximum displacement amplitude in a day becomes about 1.0 mm

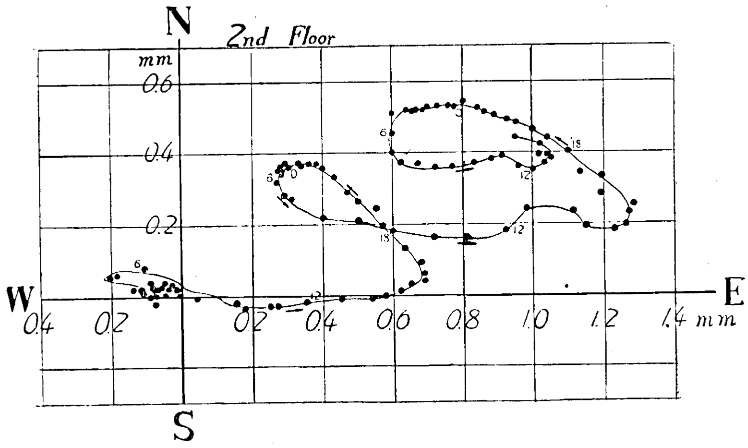


Fig. 31. Vector diagram of the house due to the sun's radiation heat.

which corresponds to the statical deformation caused by the horizontal force of about 350 kg-wt applied to the 2nd floor. This fact shows that the house deformation due to the radiation heat of the sun is large and is not negligible when we study the deformation of a Japanese wooden house.

7. Conclusion.

In the present paper, we have explained the vibration properties of a Japanese two-storied wooden house when it is subject to free vibration caused by a shock, and also to forced vibration due to unbalanced force or natural wind pressure. The house deformation due to thermal stress under the radiation heat of the sun has also been studied.

Concluding this paper, we express our thanks to the late Prof. M. Ishimoto, by whose guidance the present study has been carried out, and also to the late Yoshitaro Maeda, teacher of the Technical School, Inatori-machi, Shizuoka Prefecture, whose assistance proved valuable in the present analysis. We also wish to express our sincere thanks to Katsuzo Hosaka who constructed the present experimental apparatus designed by us. Lastly we express our thanks to the authorities of the Japan Committee for Promoting Science and Engineering for the grant in aid of the present research.

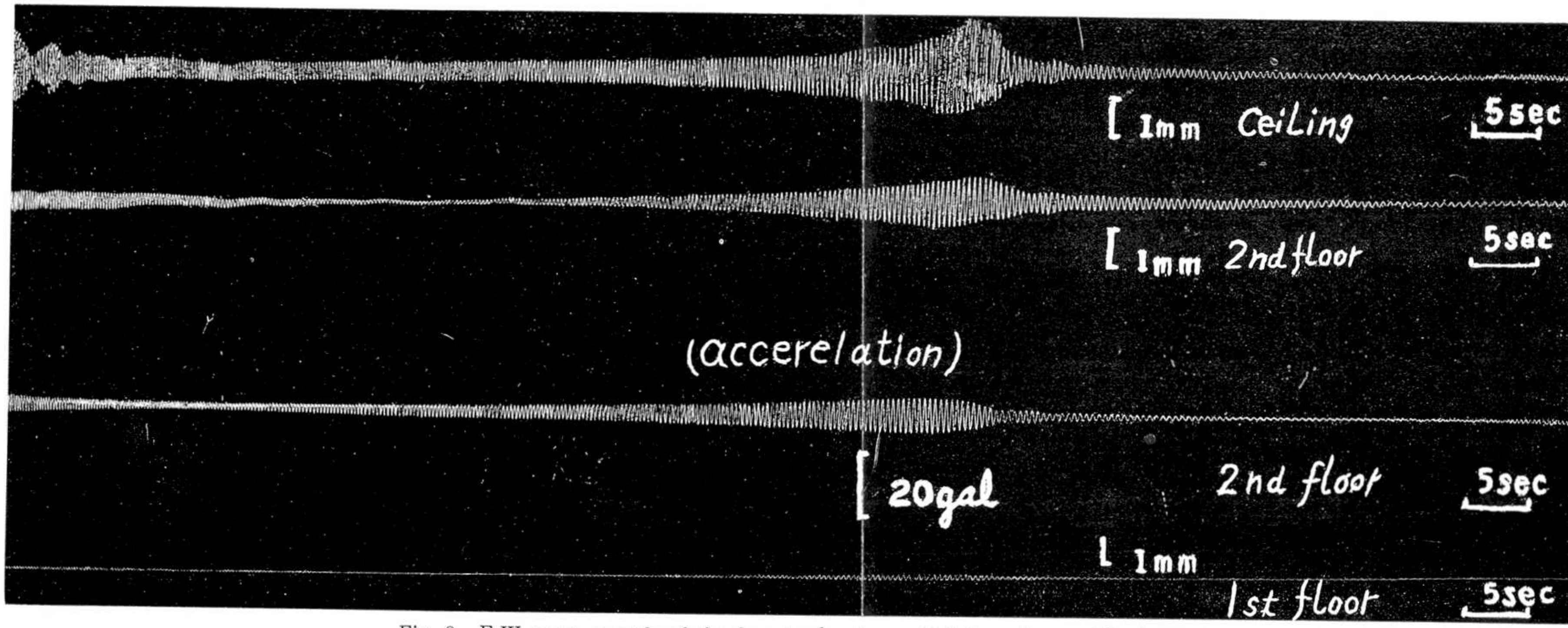


Fig. 8. E-W comp. records of the forced vibrations. Unbalanced mass M_c=3.4 kg.

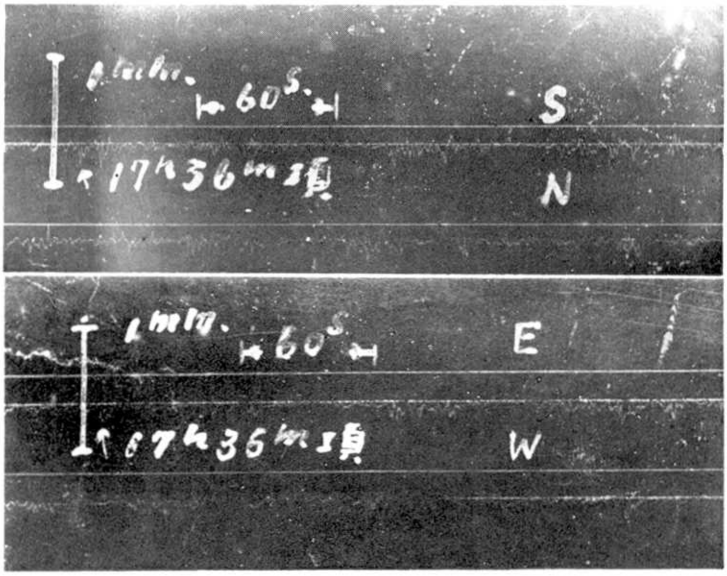


Fig. 17a. Vibration records of the house due to N-E wind.

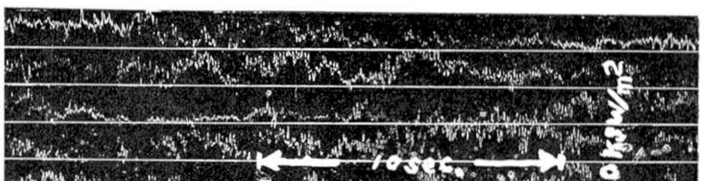


Fig. 17b. Records of N-E wind.

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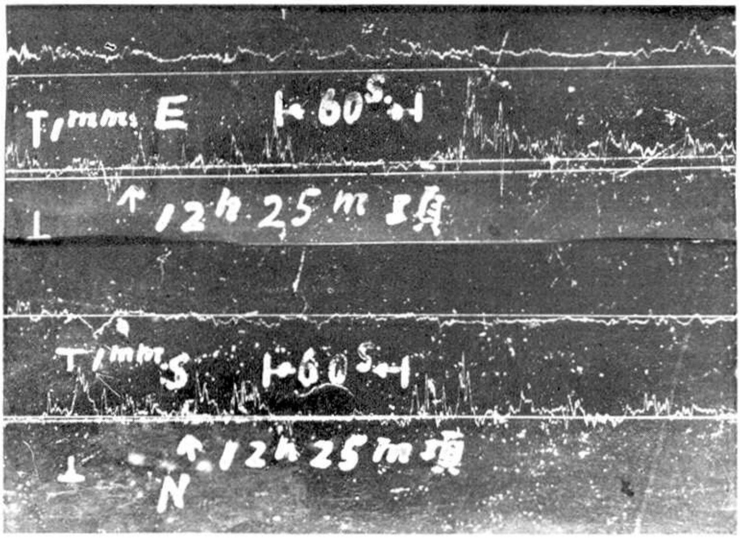

Fig. 18a. Vibration records of the house due to S-W wind.

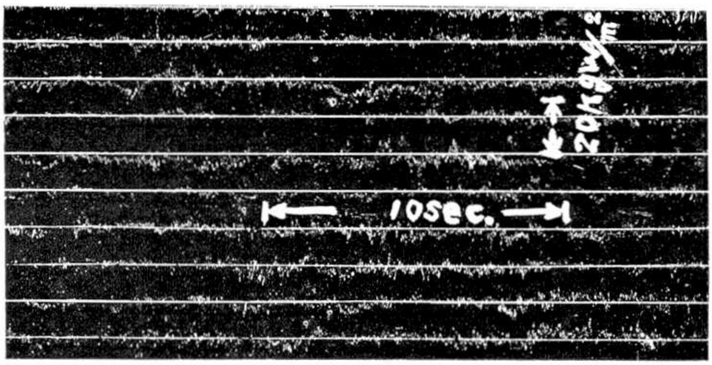

Fig. 18b. Records of S-W wind.

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8. 自然風及び起振機等による木造二階建住宅の振動

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鈴木正治

筆者達は自然風の観測結果を発表したが，此の観測と共に自然風に依る木造家屋の振動観測も合せて行つた．従来木造家屋の耐風構造の問題は静的に取扱われ自然風の息に対する動的の考慮は殆んど見当らない．然しながら鉄塔及び高層建造物等の自然風に依る振動観測の結果に就いては報告されて居る．本観測は最初は風の観測点附近に実験家屋を求むる予定であつたが，適当の家屋が見当らずその地点より南方約50米の木造二階建の家屋を選定観測する事にした．本報告は直接風の観測と対応する部分は少なく主として直接人力に依る自由振動，起振機に依る強制振動及び日射熱に依る家屋の動きに就いてである．これを総括すれば次の如くである．

i　自由振動　自己振動週期は E-W 成分は 0.31 秒～0.34 秒，N-S 成分は 0.29 秒～0.30 秒，減衰比は E-W 成分は 1.06～1.35，N-S 成分は 1.08～1.27 で，振動振幅が増加すれば自巳振動週期及び減衰比が増加する．

ii　強制振動　自巳振動週期は自由振動の場合と同様振動振幅が増加すると，E-W，N-S 両成分共に増加する．同一加力に対して両成分を比較すると，N-S 成分は静的及び共振時に於ても加力に振幅は比例するが，E-W 成分に於ては静的には比例するが共振時には比例しない．天井 N-S 成分の静的振幅はそれの E-W 成分と比較すると 0.32 倍，二階の N-S 成分の 0.41 倍となり顕著に小さい．之は N-S 成分に壁体の効果が多いものと考えられる．

iii　自然風に対するもの

a　風圧と変位　変位は殆んど風圧に比例する．天井の変位は二階の 1.4 倍～1.2 倍である．同一風圧に対して南西風に依る場合の変位は北東風に依る場合より二階及び天井共大きい．

b　週期と頻度　家屋の卓越振動週期は，家屋の固有振動週期 0.30～035 秒附近と 2.6 秒～3.2 秒附近に卓越する，又南西風に依るものが北東風より大きな週期の波動が多い．

c　週期と変位　家屋の固有振動週期 0.30～0.35 秒附近の振動変位は小さく，最も大きい変位を与える週期は 2.0～5.0 秒である．

d　家屋の平面的運動　風力に依る家屋の変位の軌道は楕円運動で，之は風向変化と家屋の構造に依るものと考えられる．

iv　日射に依るもの

家屋は日射に依り各部の温度差に依り応力を受ける．此の結果変形するのであるが，気温変化と相似な変化をなし，その変位量は一日の温度差に比例し，曇天及雨天の日は極めて小さく，その運動の経路は楕円である．各階の各成分は大体相似で夫々異つた残留変位がある．

結　語

一般の木造住宅は其の固有週期は殆んど一秒以下である故風の息の週期に依る共振は殆んど考慮の必要なく，静的の取扱ひで充分と考えられるが，木造構造物中で其の固有振動週期の長い五重塔其の他一秒以上の固有振動週期の構造物は其の設計には一応共振を考慮した動的な取扱をなすべきであると考える，

前記装置に依つて種々の振動観測の結果について述べたが，家屋の構造及び風の性質に依つて多少は異る結果はあると思われるが，将来の研究のいとぐちともなれば著者等は満足である．

筆を擱くにあたり元稲取町実業学校教官故前田芳太郎氏に対し生前に於て観測及び御協力に依て此の研究を遂行し得たもので同氏の靈に対し感謝する次第である．尚機械の設置に関しては保坂製作所長保坂勝造氏の御協力に依るもので御礼申上げ，研究費の大部分は日本学術振興会の援助に依るもので玆に感謝の意を表す．