# 38. *Experimental Study of Vibrations of Structures Caused by After-shocks of Imaichi Earthquake of Dec. 26, 1949.*

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## 1. Introduction.

If we could observe precisely the motions of structures or the motions of ground at the afflicted area of great earthquakes so as to make clear the collapsing process of structures due to earthquake, the problem of earthquake-proof buildings would make much more progress. These observations, however, being considerably difficult to carry out in practice, this problem has been hitherto attacked only in various indirect ways. Namely, the statistical and analytical studies of earthquake damage to buildings were started from the statical point of view,[1] but they have been developed gradually into dynamical treatments such as the studies of the relation between the earthquake damage of buildings and the nature of ground.[2] On the other hand, in the field of experimental studies, the measuring of vibration of buildings by means of artificial vibrational forces[3] as well as by actual earthquakes of small scale[4] has been tried many times.

These investigations showd us that the vibration problem of buildings caused by destructive earthquake are very complex and there many subjects concerning this problem remains to be treated.

Nevertheless it can be said that, since these investigation threw light on the problem of earthquake-proof construction to a considerable extent, its remarkable developement will be realized in the near future. With a view

1) R. SANO, *Rep. Earthq. Inv. Comm.*, No. 83 (1916), A, 1; B, 1.

2) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, 10 (1932), 171,
K. SEZAWA and K. KANAI, *Bull. Earthq. Res. Inst.*, 14 (1936), 164,
K. KANAI, *Bull. Earthq. Res. Inst.*, 17 (1939), 37; 27 (1949), 97.

3) T. SAITA, *Rep. Earthq.-proof Const. Comm., Japan Soc. Prom. Scie. Res.*, No. 1, 60,
*Rep. Special Comm. Fukui Earthq.*, (1950), 186-187,
K. KANAI, *Bull. Earthq. Res. Inst.*, 27 (1949), 91.

4) T. SAITA and M. SUZUKI, *Bull. Earthq. Res. Inst.*, 14 (1936),
C. TSUBOI and S. MIYAMURA, *Bull. Earthq. Res. Inst.*, 20 (1942), 291,
*Rep. Special Comm. Fukui Earthq.*, (1950), 187-190.

to obtaining some insight into the problem just mentioned, we investigated the effect of periods, displacement amplitudes and acceleration amplitudes of earthquake motions as well as the proper period and stiffness of buildings, on the strains of buildings in the after-shocks of the Imaichi earthquake.

We carried out the observations of the after-shocks, using the acceleration seismograph together with the displacement seismograph and at the same time the strains of four kinds of buildings caused by the same shocks were measured during the period from Dec. 27, 1949 to Jan. 8, 1950 at Nikko-town in the slightly afflicted area. In the next period from Mar. 22 to Mar. 25, 1950, vibration experiments by means of a vibrator were made on the same buildings.

## 2. The method of observation.

The constants of the acceleration seismograph and the displacement seismograph used in the observation were as follows:

acceleration seismograph; period=0.1 sec, 1 mm=2.2 gal,

displacement seismograph; period=4 sec, magnification=12.

The four kinds of buildings with which we experimented were a wooden shed, a wooden building covered with mortar (an electric distributing station), a wooden dwelling house of Japanese temple type and a wooden granary covered with soft stone. The sketch of these buildings are shown in Figs. 1–4.

The strains of buildings were measured in a way so that the deflections of a part of column at some height above the base relative to the base may be recorded on a revolving smoked paper magnified mechanically about 50 times. Marks × in Figs. 1–4 show the location of the apparatus.

The vibrator which consists of one rotating wheel with eccentric weight driven manually was set on the place of mark ⊙ in Figs. 1–4. The wheel was driven faster than the proper period of a test building and then set free

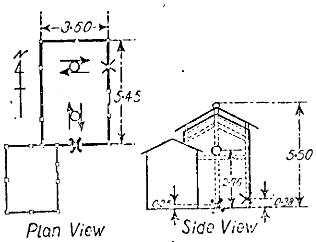


Fig. 1. Sketch of the wooden granary covered with soft-stone. Marks ○ and × indicate the locations of the vibrator and the apparatus.

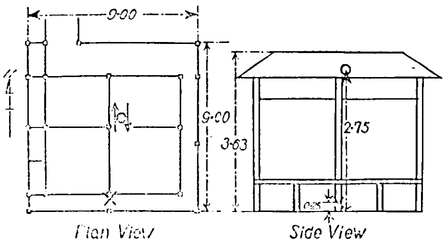


Fig. 2. Sketch of the wooden dwelling house of Japanese temple type. Marks ○ and × indicate the locations of the vibrator and the apparatus.

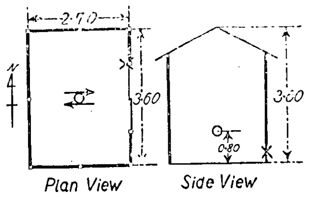


Fig. 3. Sketch of the wooden building covered with mortar. Marks ○ and × indicate the locations of the vibrator and the apparatus.

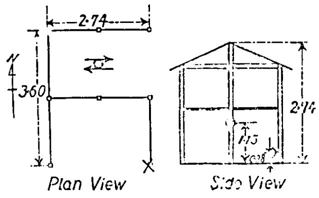


Fig. 4. Sketch of the wooden shed. Marks ○ and × indicate the locations of the vibrator and the apparatus.

in a state of free rotation. It keeps on running for quite a long time diminishing its speed gradually. Eccentric weight of 1 kg is set at the radius of 18 cm.

### 3. Results of observations and interpretation of them.

Displacement seismogram, acceleration seismogram and record of strain of building due to after-shocks are shown in Figs. 5, 6.

(i) *Cases of EW direction of the wooden granary covered with soft stone and the dwelling house of Japanese temple type.*

Using the observed records, we obtained the relation of vibration periods to their frequency, and that of vibration amplitudes to their periods, regarding the accelerations as well as the displacements of the after-shocks and strains of buildings due to the same shocks.

On the other hand, we also got the relation between the vibration period and amplitude of each building in the case of artificial vibration experiments. The results of them are shown in Figs. 7, 8.

Two figures tell us that the vibration amplitudes of after-shocks are large at frequent vibration period. In the case of the granary, it seems that both the frequency of vibration period and the amplitude of vibration strain due to after-shocks have two peaks at nearly the same vibration period, one of which corresponds to the vibration period where the period frequency and the amplitude of acceleration of after-shocks are large,and the other corresponds to the vibration period where the amplitude of strain of building due to artificial vibrational force is large.

In other words, the strains of the granary caused by after-shocks grow larger in two cases, that is when the acceleration amplitudes of shocks are large and when the proper period of the building coincides with the period of shocks, and the strains due to the former case are several times larger than those due to the latter.

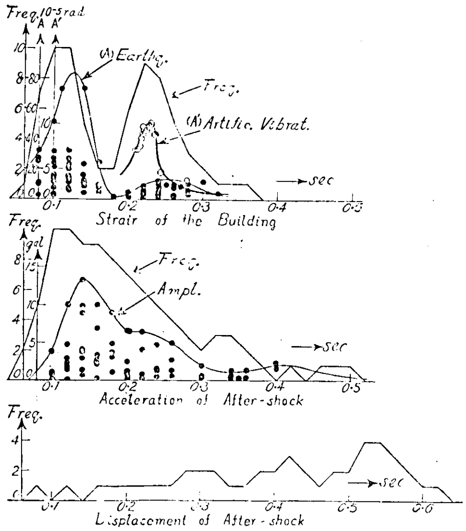


Fig. 7. Case of *EW* direction of the wooden granary covered with soft-stone.

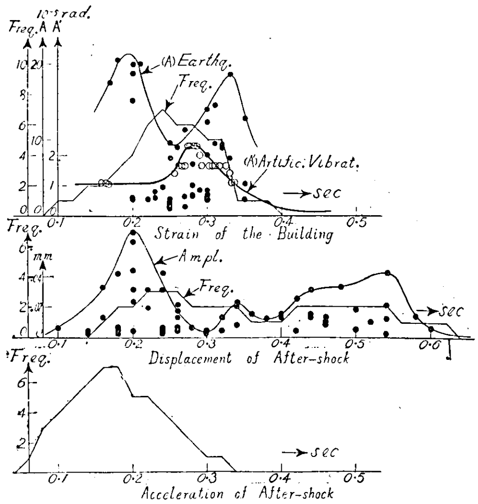


Fig. 8. Case of the dwelling house of Japanese temple type.

In the case of the temple-type house, as shown in Fig. 8 there are two peaks in the strain amplitudes due to after-shocks, but the period frequency has only one peak which is relatively flat. One of the two peaks of the strain amplitudes of the temple-type house corresponds to the vibration period of the large displacement amplitudes of after-shocks, and the other corresponds to the large strain amplitudes in artificial vibration experiments. The peak of the frequency of strain period approximately corresponds to that of the frequent displacement of after-shocks.

Thus we reached the following view, as already stated, that the vibration of wooden granary covered with soft stone was influenced by the accelerations of after-shocks, but the vibration of wooden dwelling-house of Japanese temple type was rather sensible to the displacements of after-shocks, and both buildings have the tendency to induce their free vibrations whether great or small.

(ii) *Cases of NS direction of the wooden granary covered with soft stone, the wooden building covered with mortar and the wooden shed.*

In these cases, using the observed records, we obtained the relation between vibration period and their frequency, regarding the accelerations as well as the displacements of the after-shocks and strains of each building due to the same shocks. On the other hand, we obtained the relation between vibration period and amplitude of each building in the case of artificial vibration experiments. The results of them are shown in Figs. 9–11.

It will be seen that, in these three cases, as the maximum frequency of strain period of each building is nearly equal to both of the maximum frequency of acceleration period of after-shocks and proper period of each building, it is naturally not clear which of them has more influence on the strain of building.

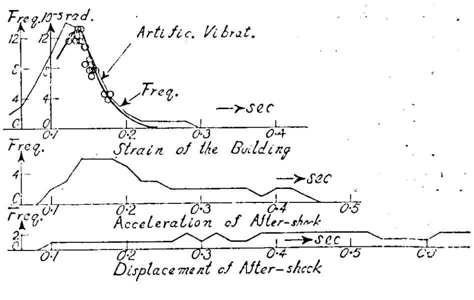


Fig. 9. Case of *NS* direction of the wooden granary covered with soft-stone.

## 4. Conclusion.

The vibration problems of buildings caused by earthquake were to some extent made clear by investigating the displacement, the acceleration of after-shocks and strains of various kinds of buildings caused by those shocks in the Imaichi earthquake of Dec. 26, 1949.

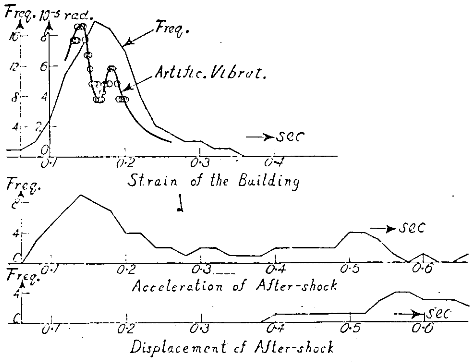


Fig. 10. Case of the wooden building covered with mortar.

The results of these investigations showed that relatively rigid buildings suffered by accelerations of successive earthquake motions, but relatively flexible buildings were rather affected by their displacements.[1]

And, free vibrations of buildings seems to be excited considerably in the case of relatively flexible buildings, but in the case of relatively rigid buildings the degree is rather low. At any rate, as free vibrations of buildings will be excited more or less by earthquake motions, it is

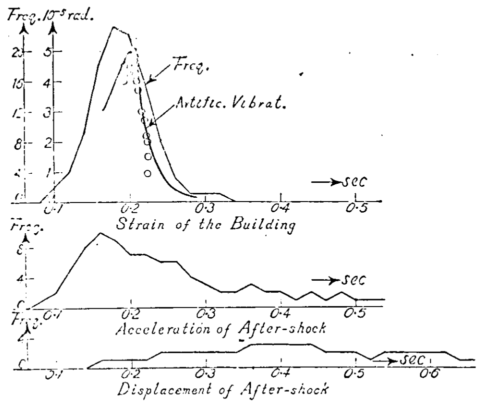


Fig. 11. Case of the wooden shed.

1) K. KANAI, *Bull. Earthq. Res. Inst.*, 25 (1947), 64, Fig. 4.

injurious for buildings to have proper periods near to the frequent periods of earthquake motion.

The phenomena of damage done to buildings in the past great earthquakes are likely to be explained to a degree through the results just mentioned.

In conclusion, we wish to express our hearty thanks to Mssrs. M. Suzuki, T. Tanaka and K. Osada, with whose aid the present investigations were successfully made.

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## 38. 今市地震の余震による建物振動の觀測結果

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今市地震の余震の加速度及び變位とその余震による種々の建物の歪とを觀測し，後にこれらの建物について人工的振動試驗を行つた結果，次の事柄がわかつた．

即ち，貼石木構造の藏のような比較的に剛構造物の地震動による歪は地震動の加速度振幅に支配され安く，建物自體の自己振動を多少誘發される．これに反して，神殿作の住居のような比較的に柔構造物の地震動による歪は，むしろ地震動の變位振幅の影響を受け，建物自體の自己振動が相當に誘發される．

尙建物の歪は，何れの場合にも，地震動の大振幅の部分の繼續時間に非常に支配される．

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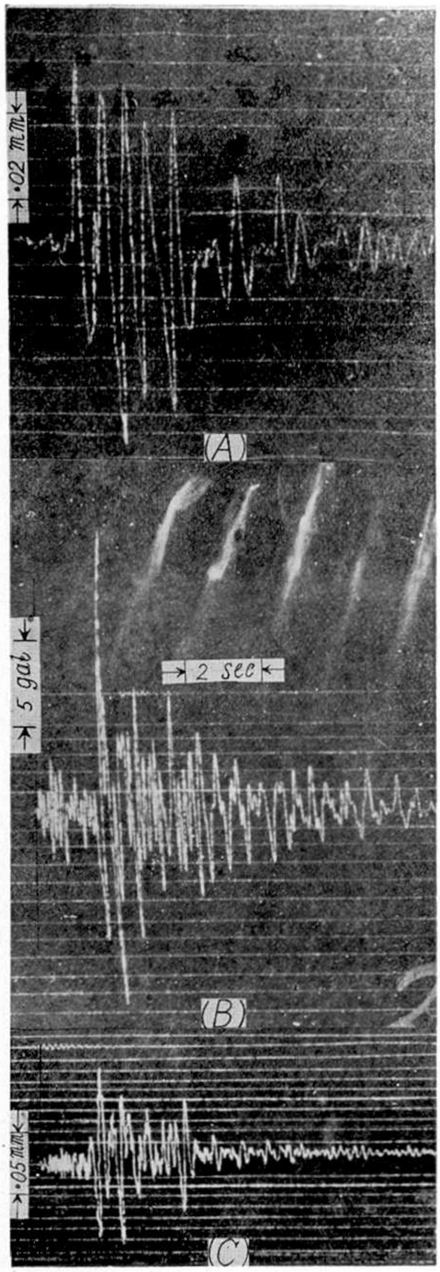


Fig. 5. (A); Displacement seismogram, (B); Acceleration seismogram, (C); Record of strain of the wooden building covered with mortar.

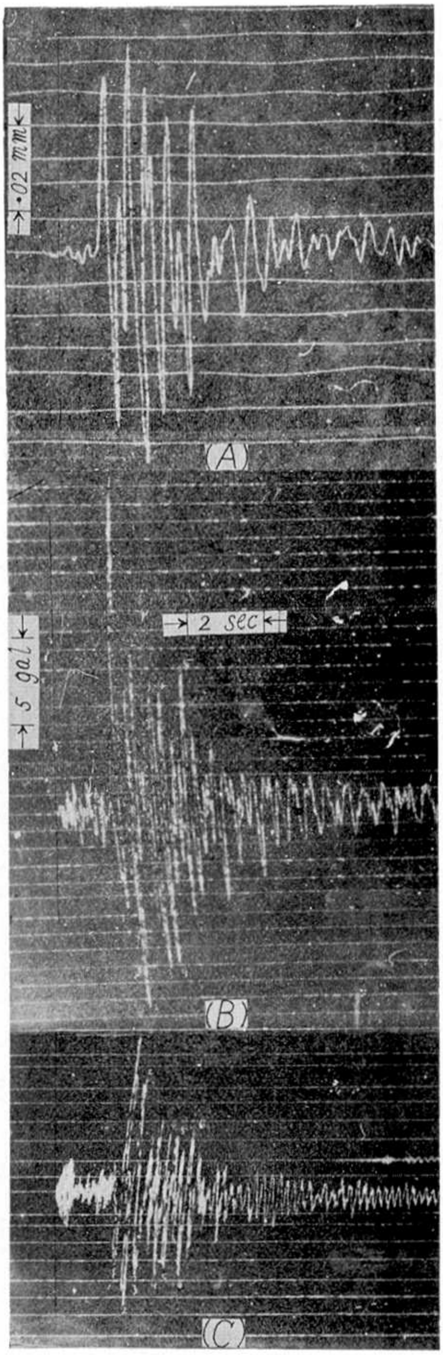


Fig. 6. (A); Displacement seismogram, (B); Acceleration seismogram, (C); Record of strain of the wooden shed.

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