12. *On the Damages to Buildings due to Earthquakes.*

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1. The problem of destruction of a building due to great earthquakes were investigated experimentally by Omori, Imamura and others[1]. The mathematical treatment of it was made by many authors: Sano, Suyehiro, Majima, Mononobe, Muto, Taniguchi, Sezawa, the author and others[2]. From our past investigations[3], owing to the dissipation of vibrational energy into the ground, we showed that the resonance amplitudes may be smaller by increasing the effective stiffness of a structure relative to that of the ground. The same problem was dealt with experimentally by Ishimoto[4] and Saita taking into account of the vibratory motion of the ground. They concluded that the damages to the buildings due to earthquakes will be mostly depended on the proper predominant period of seismic vibrations on each ground.

But the standpoints, on which these authors are based, are mainly to apply the principle of pure vibration problem. As a matter of fact, the dynamical actions causing damages of the buildings subjected to earthquake are not steady pure vibrational force.

The first section of the present paper discusses theoretically and model experimentally the transeint vibration problem of a structures, and the second section shows that there were large number of damages to buildings caused by the unequal settling of foundation with the data of the past great earthquakes of 1891-1947. whereas for the third section, we investigated theoretically the special cases of earthquake-damages to Japanese-style buildings.

2. *The transient vibration problem of a structures.*

In order to clear the vibrational mode of a structures subjected to the earthquakes, we investigated theoretically the shearing motion of

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1) See the *Rep. Earthq. Inv. Comm.*
2) See the footnote of the *Bull. Earthq. Res. Inst.*, **10** (1932), 767.
3) K. Sezawa and K. Kanai; *Bull. Earthq. Res. Inst.*, **13** (1935), **14** (1936).
4) M. Ishimoto; *Bull. Earthq. Res. Inst.*, **10** (1932)—**14** (1936).

the structure from the transient point of view. We used Heaviside's operational calculus in solving the problem. These results were ascertained model experimentally by means of the vibration table. The model is the singled-storied, one-span framed structure which has construction of two thin steel plates and one thick wooden plate. The results of the experiments are shown in Fig. 1.

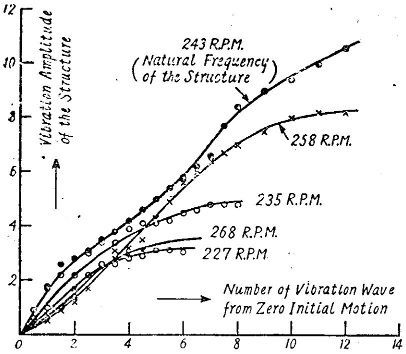

Fig. 1.

These investigations showed that the motion of a structure reaches to the maximum amplitude by repeating several times the displacement of the ground with zero initial displacement, when the period of displacement of the ground differes from the natural period of the structure, while the motion of a structure does not approach to the asymptote even by repeating more than one hundred times the displacement of the ground with zero initial displacement when both periods are equal, that is, in a resonance-like condition.

The observed fact in connection with the vibrational mode of some structures caused by the Nankai earthquake of Dec. 21, 1946, which were made by a few attentive people of Kochi city in the seriously damaged region, are seems to fairly agreed with the results of this section.

3. *Dynamical actions causing damages of the structures due to earthquakes.*

Investigations in the area devastated by past three great earthquakes[1] were carried out by us from the point of view of finding the relation between damage to buildings caused by the earthquakes and the motion of the ground. From these investigations, we found out that the serious damage to Japanese frame houses situated on the soft ground at the time of the great earthquakes were originated not only from the coincidence of the natural periods of the houses and the soft ground or from the large vibrational amplitudes of the soft ground, but also in that the soft ground beneath the buildings are liable to yield unequally.

In order to make more clearly the dynamical actions causing damages

1) Nagano Earthq. of July 15, 1941, Tōnankai Earthq. of Dec. 7, 1944, Nankai Earthq. of Dec. 21, 1946.

of the structures by the earthquakes, we studied the relation between the totally-destructed and semi-destructed buildings and the ground conditions with the data of the past great earthquakes of 1891-1947. The relation of them are shown in Fig. 2.

In this figure, the notation of TOTALLY, SEMI and NUMBER represented the number of the totally-destructed, of the semi-destucted houses at each village or town, and the number of villages and towns respectively. From the above investigation, we found that the damages to buildings subjected to pure vibrational forces had occurred mainly on the rigid ground with safe or else totally-destructed buildings, whereas the damages to buildings caused by the unequal settling of foundation arose mostly on the soft ground with large number of semi-destructed buildings.

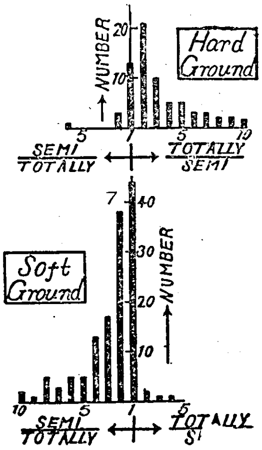

Fig. 2.

4. *Theoretical investigation to the special cases of earthquake-damages to Japanese-style buildings.*

We have calculated the maximum bending moment of the column and the acceleration of the top of a single-storied framed structure with endless extent of the series of successive spans. The notations used are as follows...y; transverse deflection of the columns, m; concentrated mass at floor, E, I, ρ, a; Youngs modulus, sum of moment of inertia of crossection, density, and sum of crossectional areas of the columns respectively. The equation of motion of the bar is expressed by

$$EI\frac{\partial^4 y}{\partial x^4}+\rho a\frac{\partial^2 y}{\partial t^2}=0. \qquad (1)$$

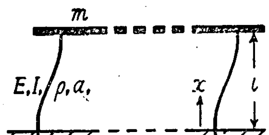

Fig. 3.

When the bottom of each column is oscillating horizontally with amplitude ξ and with period $2\pi/p$, the boundary clamped conditions at the bottom, are written by

$$x=0; \qquad y=\xi\cos pt, \quad \frac{\partial y}{\partial x}=0. \qquad (2), (3)$$

If the roof construction is extremely rigid, the clamped boundary conditions at the top may be written as follows;

$$x = l; \qquad m\frac{\partial^2 y}{\partial t^2} - EI\frac{\partial^3 y}{\partial x^3} = 0, \quad \frac{\partial y}{\partial x} = 0. \qquad (4), (5)$$

Substituting the solution of (1) in the conditions (2)–(5), and writing $n^4 = \rho a p^2/EI$, $\nu = m/\rho a l$, we get finally the equation of the ratio of the maximum bending moment of the column (B. M.) and the acceleration of the top of the cloumn (Accel.). The above equation becomes as follows:

$$\rho a l^2 \frac{Accel.}{B. M.} = \frac{(nl)^2 Q}{P\max.} \qquad (6)$$

where

$$\left.\begin{aligned} P &= A\cos nx + B(\sin nx + \sinh nx) - C\cosh nx, \\ Q &= A\cos nl + B(\sin nl - \sinh nl) + C\cosh nl, \\ A &= 2\sinh nl \cos nl + nl\nu(\cosh nl \cos nl - \sinh nl \sin nl - 1), \\ B &= 2\sinh nl \sin nl + nl\nu(\cosh nl \sin nl + \sinh nl \cos nl), \\ C &= 2\cosh nl \sin nl + nl\nu(\cosh nl \cos nl + \sinh nl \sin nl - 1). \end{aligned}\right\} \qquad (7)$$

We have plotted the results of the numerical calculations in Fig 4. In this figure, the vertical strips indicate the natural frequency of each cases.

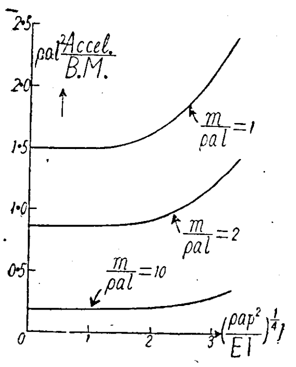

Fig. 4.

From this mathematical investigation, it may be seen that the heavy house-top will be liable to fail the vertical members of a building, and roof tiles will be liable to fall at higher frequency of seismic disturbances such, that seismic vibration on the rigid ground. We do not doult that these results will be useful to explain various conditions of earthquake-damages to Japanese-style buildings.

5. *Concluding remarks.*

It will be seen from these studies that the dynamical reasons of the damages to Japanese-style buildings at the time of earthquakes are of two kinds, one being of the condition subjected to pure vibrational forces and the other of the secondary condition caused by seismic vibrations, namely, of the unequal settling of foundation of the building.

In conclusion, I wish to express my thanks to Messrs. T. Tanaka, T. Suzuki and S. Kaneko, who assisted me much in the course of the present investigation.