VIBRATIONS OF BUILDINGS IN JAPAN (IN TWO PARTS)

PART I

SMALL AMPLITUDE VIBRATIONS OF ACTUAL BUILDINGS

By

HIROSI KAWASUMI[1] and KIYOSHI KANAI[1]

INTRODUCTION

Japan is well known as a land having a high degree of seismicity. We Japanese have long sought measures of limiting the disastrous effects of earthquakes. Aseismic construction methods, worthy of note, were achieved in the first quarter of this century. Many structures constructed during this period have proved highly resistant in several destructive earthquakes.

Present Code requirements result in a very rigid building and up to current times the height was restricted to 100 feet or less. The stiffness of our buildings is generally much higher than in comparable structures in American and European countries. Economy of construction and space utilization requires, however, that we endeavor to find a more efficient and rational criteria . Efforts are being made in our country to find such criteria in the study of the dynamic behavior of buildings in strong earthquakes.

Theoretically, the motion of a vibration system like a building when subjected to earthquake motion is determined by its vibration characteristics and the spectrum of an earthquake motion. In recent years many spectra of strong motion earthquakes have been worked out by American scientists (1), (2) and (3) and a standard form of the earthquake spectrum has been deduced for engineering use. Japanese seismologists are endeavoring to clarify the modulation of earthquake motion due to the subsoil conditions. The results of these endeavors are given elsewhere (4). At the present time, however, we now only have to know the vibrational characteristics of a building to deduce its dynamic behavior in a strong motion earthquake and to discuss its seismic stability.

In the early studies, only the period of free vibration was considered as it gives a clue to the rigidity of the building. Dynamically, however, the damping is no less important as it curtails resonance with the earthquake motions. These two important factors of building vibrations recently were found to be affected by the subsoil conditions. The dissipation of energy into the ground has been found to contribute to the damping of building vibrations, in addition to the effects attributable to the internal friction and viscosity of the building materials.

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1. Earthquake Research Institute, Tokyo University

ANALYSIS OF STRUCTURAL RESPONSE

The yielding of the subsoil induces a rocking motion in the vibration modes. This and other cushioning actions of the ground at the time of a strong motion earthquake serves more or less to relieve its destructive action.

Next, we should state that there is a modification of the vibrational characteristics when the vibrations are of large amplitude, which occurs because of the non-linearity of the stress-strain relationships of the building materials and the ground. This item is the subject of Part II of this paper. In this part only the vibrational characteristics of buildings in the small amplitude range obtained by shaking tests and earthquake observations, are considered. Some theoretical verification is also given.

SHAKING TESTS

The stability of a building when subjected to a strong motion earthquake is dependent to a large degree on the response amplitude of the building vibrations, which in turn is related closely to the structural details of the building. The detection of structural defects, if any, and the determination of the stability of an actual building are of importance from an engineering point of view and also for the welfare of the people. In the post-war period in Japan, such building tests have been requested frequently by the owners or users of buildings damaged by fire. In compliance with such requests, engineers have conducted vibration tests using shaking machines. The results have extended greatly our knowledge of the vibrational characteristics of buildings.

We shall summarize herein the modes, the periods and the dampings of the vibration of actual buildings as deduced from these shaking tests. The data, as reported by the observers, was entered on separate cards for each building. The location, history, the structural type, the plan, sections, the foundation and the subsoil conditions with the instruments used in the measurements, their characteristics, and the observed results were tabulated on these cards. A separate description of interesting facts contained in the complied information is contained herein.

MODES OF BUILDING VIBRATIONS

More than twenty years ago, K. Suyehiro (5) suggested the possibility of three kinds of modes in building vibrations: 1. A transverse (flexural) vibration, 2. A shearing vibration, and 3. A rocking motion. As stated previously, the height of our buildings is restricted by the Building Code with the usual height-to-width ratio being small in consequence. Most of the ratios are below two with those of over four being very rare. Thus, it was to be expected that the shearing vibration would predominate theoretically. However, since the actual buildings cannot be represented as simple bars, closer examination will prove the difficulty in distinguishing between the first two kinds of vibration. Recently, to investigate the rocking and flexural vibrations, we have introduced seismographs for vertical components of motion for use in measuring the inclination of different floors. Previously, the distribution along the vertical axis of the maximum horizontal deflection of the building at the time of resonance (hereafter called the deflection curve) was examined

and the deflection was analyzed into the two kinds of vibration. The existence of rocking motion makes a straightforward separation a very difficult matter without the additional observation of the inclination of each floor.

Let us first examine the deflection curves along the vertical axes of a number of important buildings. Observed amplitude was reduced to the standard value responding to the shaking machine installed on the roof and having a unit moment of weight in kg cm per cm per one square meter of all floor and roof area. These values are plotted in Fig. 1 versus the heights of their points of observation. The deflection curves thus obtained show a comparatively systematic trend. All of them have finite displacement at the base while most of them show the similarity of shearing vibration. However, the boundary conditions at the base are to be explained by those of the flexural vibrations and the rocking motion. The deflection curves in the transverse direction of a few slender buildings are remakably straight as is characteristic of the rocking motion. On some of these buildings inclination of the roofs and basement floors was measured. The results are shown in Fig. 2. At the Fuse Middle School in Osaka Prefecture (6), the inclination of the roof and the basement were exactly the same and equal to the angle between the deflection curve and the vertical axis, showing that the building rocked as a rigid body. This shows that no horizontal stress is induced in the building, and a reaction is exerted by the ground only in the vertical direction, the amount, however, being negligible in comparison with the force of gravity. The apartment houses at the Hitachi Mine in Ibaraki Prefecture, when tested by a shaking machine showed a larger inclination at the roof than at the basement. This indicates the flexural deformation of the vertical axis of the building.

If such an inclination of the basement of a building accompanies the vibration, some parts of the stress is shared by the ground and the destructive power will be reduced by that amount. It is therefore important to examine whether such tilting of the base of a larger building actually occurs or not in its vibration. The Daiichi Sōgo Life Insurance Co. Building in Kyobashi, Tokyo, 28.8 meters tall and 30 meters wide with a depth 23.9 meters, proved such inclination in each direction (7), although the amount of the horizontal deflection attributable to it is about one fifth of the total. (See Fig. 3).

On the other hand, the horizontal displacement of the basement sometimes amounts to 40 percent of that on the roof. This also may exert some beneficial effect in releasing the seismic force, the ground serving as a cushion to the building. These points will be discussed theoretically in the last section of this paper.

In our vibration measurements, only one shaking machine is used, so that if its position does not coincide with the centers of gravity or stiffness, other modes than those already mentioned are set up in the building's vibrations. The commonest of these is the torsional vibration around a vertical axis. Even when the shaking machine is set at the middle of a long building, and transverse vibration is applied, an harmonic with two nodes like a free-free bar is sometimes observed. Needless to say that similar harmonics in the vertical mode are set up

if the frequency of the shaking machine can be increased sufficiently; but, due to the lack of the power which would be required, we have seldom observed such harmonics. One unquestioned example, however, was obtained and reported by the team of Waseda University (8) in a test of the Matsuzakaya Department Store on Ginza Street, Tokyo. The deflection curve (see Fig. 4.) resembles the second harmonics of the shearing vibration, the period being exactly one third of the fundamental as postulated from the theory, but the boundary conditions at the basement are not harmonious with the theoretical requirements.

PERIODS OF FREE VIBRATIONS

Since the beginning of this century, the natural periods of structures were observed in Japan to obtain the clues to the stiffness of the structure. Usefulness of this method was actually proved by shortening of the period, with corresponding increase of rigidity by the repair work of every building damaged in the great Kanto earthquake of 1923. T. Taniguchi (9) formulated the following criteria:

$$T = N\ (0.07 \sim 0.09) \quad \text{sec} \qquad \ldots\ldots\ (1)$$

to determine the soundness by the period T in relation to the number of stories N of the building. In 1952 F.P. Urlich and D.S. Carder (10) deduced a similar mean relation:

$$T = 0.006\ H \quad \text{sec} \qquad \ldots\ldots\ (2)$$

where H represents the height of the building in feet. In determination of this formula they used more than 3,000 vibration observations made by the United States Coast and Geodetic Survey (11). The Joint Committee on the Lateral Forces of Earthquake and Wind of San Francisco (12) proposed another formula:

$$T = 0.05\ H/\sqrt{D} \quad \text{sec} \qquad \ldots\ldots\ (3)$$

for the criterion of soundness. While the mean relation for all the American Buildings was expressed by:

$$T = 0.06\ H/\sqrt{D} \quad \text{sec} \qquad \ldots\ldots\ (4)$$

In the above equations H and D represent the height and the depth of the structure in feet, respectively.

The writer has examined the periods of Japanese buildings to determine whether the effect of the depth on the period is similar to the above relation. The effect of the height H was eliminated by taking the ratio of the periods of longitudinal and transverse vibration of individual buildings, and comparing these ratios with ratios of the depths in each direction. These findings were then plotted on log-log section paper. Although the data were meager, and some exceptions were noted, the trend was similar to the corresponding diagram obtained from the more voluminous and systematic data observed in America, as expressed by formula (3) or (4) of the San Francisco Committee.

The writers proceeded to calculate $H/\sqrt{D}$ for every period of well-defined longitudinal and transverse vibration, and made a corelation diagram between the period and the value of $H/\sqrt{D}$ as shown in Fig. 5. The parameter of the line in this diagram is the coefficient of equations similar to (3) or (4), above.

The writers call the reader's attention to the fact that many of our data are obtained from measurements of defective buildings more or less damaged by fires in World War II. A glance at Fig. 5 shows that the line with the parameter 0.05 fairly well represents the mean relation of all the data excepting those of the buildings badly damaged in the great Kanto earthquake. The points for most of the newly built buildings distribute along the line with the parameter 0.04, clearly indicating the high stiffness of the average building in this country. In this connection, we must remember that most of these buildings are of reinforced concrete, and those of steel frame construction are very few in number.

We have already stated that a second harmonic oscillation of a shearing vibration type was observed in the vibration test of a department store on Ginza Street, Tokyo. According to the observation of T. Naito, N. Nasu and others, the periods were 0.205 sec and 0.245 sec corresponding respectively to the fundamental periods 0.62 and 0.75 sec of the longitudinal and transverse vibrations. They have also reported that the period of the tortional vibration around the vertical axis of a building is about two thirds of the fundamental period of the flexural or shearing vibration (6).

DAMPING CONSTANTS

There is no need to stress the importance of damping in the problem of aseismic construction. In his American lecture on "Engineering Seismology" in 1932, K. Suyehiro dealt with this matter and suggested that the damping may increase with the frequency of the free vibration of a building. His inference was based on the nature of firmoviscosity of materials in general, although this was based on very meager observational data at that time. As his data were obtained from vibration observations of actual structures, he gave notice to the fact that the damping constants he obtained must have included the contribution of the dissipation of energy into the ground. Later, K. Sezawa and one of the present writers (13) proved theoretically that the vibration energy of a building dissipates into the ground in the form of elastic bodily waves. The effect of this dissipation is proved to be exactly similar to that of usual viscous damping, although it increases with the vibrational frequency as in solid viscosity. These points have been verified by a number of theoretical studies on actual buildings (14). The elastic waves radiating from vibrating buildings into the surrounding ground were actually observed on several occasions (15). Although the role played by the ground on the damping of building vibrations has been verified, quantitative relations of these effects are yet to be determined both theoretically and experimentally. New determination of the coefficient of internal friction has yet to be made, and, furthermore, the determinations of the damping constants of actual buildings are insufficient in number to establish quantitative relations with the concomitant factors (16) and (17).

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Some efforts, however, have been made to collect available data on damping, and to determine if possible the constants from materials at our disposal. The results are also tabulated in Table 1. It is to be mentioned here that the accuracies of our determinations are not high owing to the uncertainty in the period determination in the plots of resonance curves. Accordingly no elaborate calculations were made except the usual procedure to determine the damping constant in percent of the critical from the width of the resonance curve at the amplitude $1/\sqrt{2}$ of the maximum. Our experience has shown that the accuracy of period determination can be raised by the differentiation of the t(n) curve, where t(n) denotes the epoche of a definite phase of the n-th vibration after the revolution of the unbalanced weight of the shaking machine was set free and began to decelerate when its speed reached the maximum.

Now let us examine the relation of the damping constant with the other related factors. Plotting the damping constant in percent of the critical, h, versus corresponding period T on a log-log section paper, we obtain Fig. 6 in which we cannot but perceive a remarkable negative correlation between these values. Notwithstanding the fact that points scatter considerably, the mean trend shows that the damping constant is inversely proportional to the n-th power of the period, where the exponent n appears to be about unity or a little larger. According to Suyehiro's view the exponent is equal to unity, while other theories show the possibility of its being greater. We shall have recourse to these theoretical considerations in the next section.

From the theories of Sezawa and others the damping is expected to increase with the dimension of the base of the building and decrease with the rigidity of the ground material. To examine these points, the writers adopted the approximate empirical relation

$$h = CT^{-1} \qquad \ldots\ldots\ldots (5)$$

for the moment, and multiplying h by T we eliminated the effect of the latter on the former. One of the writers has reported (18) that the ratio of the damping coefficients which are proportional to h/T in the present notation is linearly related to the corresponding ratio of the depth and width of the same building. But in reality, this is nothing but the confirmation of the two relations (3) and (5) above mentioned. In order to reveal the true contribution of the depth of the building on the damping constant, we have to use the ratio of the Th values in both directions instead of the simple ratio of the damping coefficients. About two thirds of these ratios in the available data showed negative correlation with the ratios of the depths in corresponding directions, although the number of available data at present is not sufficient to establish a definite relation between these factors. The dots of all the data of Th plotted against the corresponding depth D were very divergent notwithstanding the data increased in number. We could neither discern from it any definite trend on the relation between the factors in question, nor find any clue on the effect of subsoil conditions on the Th values. We hope to be able to discuss these correlations on more systematic and ample data in the near future.

BUILDING VIBRATIONS IN MINOR EARTHQUAKES

Observations of building vibrations in Japan dates back to the last century. Resonance phenomena were found and reported to the first conference of the International Seismological Association held at Strasbourg in 1901 (19). These and other observations made up to 1931 have been summarised in K. Suyehiro's American lectures.

In those years such observations were made mainly to detect the periods of free vibrations, and occasionally to determine the ratio of maximum amplitudes on the building and on the neighbouring ground in the same earthquake. In later years, however, more systematic observations were carried out to verify the results of shaking tests, or to reveal the modes and dampings of the building vibrations. Of these the elaborate studies of T. Taniguchi and H. Kobayashi (20) are first noted. They observed earthquakes on different stories simultaneously at three different buildings. At the Nikkatsu Building at Hibiya near the Imperial Palace in Tokyo, they obtained four seismograms on high speed recording drums of the same earthquakes on different floors, that is the fourth underground basement floor, the first, the fifth and the ninth floors respectively. They then read off the displacements on the records every 0.02 second and deduced true displacements on these floors by the usual term by term integrations of the equations of motions of the seismometers. They thus found the mode of vibration of the building to vary from time to time remarkably. Another series of studies to be mentioned are the perennial observations of K. Kanai and others (21) to reveal the effects of different subsoils on the vibrations of the same type of four story monolithic pillarless feroconcrete building in different parts of Tokyo. They observed earthquakes simultaneously not only at the basement and on the roof of a building but also in parallel at other buildings or at a standard station, for which the Earthquake Research Institute of Tokyo University was chosen. They could thus determine the foundation coefficient, that is the ratio of the amplitudes of the earthquakes at one locality with those observed at the standard station, as well as the magnification factor of the amplitude on the roof as compared with that on the basement. From the latter factor, which depends on the period of motion, they could infer a type of resonance curve and obtain a clue on the damping constant of the vibration of the building. In the above procedure assumptions were made that 1) the building vibrations at times reach 100 percent resonance, and 2) the displacement at the basement is equal to the earthquake motion undisturbed by the motion of the building. But we are now of the opinion that the last assumption is not the least rigorous theoretically. One of the writers has analysed the seismograms obtained at the sixth floor and the basement of a steel framed concrete building of the Hosei University in Tokyo (22). He could thus obtain similar spectra from both of the seismograms to prove the above mentioned consideration actually, as there could be found similarly marked peaks at the same periods which are identical with the proper periods as found by the shaking test of the building. Theoretical verification on this point is also found in the next section.

THEORETICAL VERIFICATIONS

From the data above mentioned we could infer some noteworthy

features of building vibrations presumed to be of an importance not restricted to our country, and requiring some theoretical verifications.

The first point to be considered is the necessity of the revision of the equations of motions to include those of the rotations of all the floors around horizontal axes, and the horizontal motion of the basement. In the equations the effect of the subsoil conditions must also be taken into account since it also contributes to the damping. We have already obtained such equations in cases where a building rests on a semi-infinite solid body and is subjected to a seismic transverse wave emerging vertically to the surface. To set forth such equations is very cumbersome and prohibitive in the limited space of this paper, so that only the results so far obtained will be stated herein. Similar problems were solved 20 years ago by Sezawa and one of the writers as previously stated. We have now improved our findings by also taking the Rayleigh wave into consideration. The solutions of some simple cases have been obtained by Y. Sato and R. Yamaguchi of the Earthquake Research Institute using the numerical values of elastic vibrations responding to periodic forces applied on the circular area on the surface as worked out recently by I. Toriumi (23). For this data we are very thankful since our study could never have been made without the latter's laborious calculations. Among the results already obtained we will here summarise only 1) the case of rocking motion combined with a horizontal motion of a rigid cylinder placed on the surface due to incident transverse waves, and 2) the horizontal motion of an elastic one-mass system standing on a circular base on the same surface.

In the first case, there appears to be a resonance peak in each of the responding translation and the rotation of a rigid building, with the radius r_0, the height 2ℓ, and the density ρ_B, at the same period given by

$$T = \frac{2\pi}{1.12}\left(\frac{r_0}{V_S}\right)\left(\frac{\ell}{r_0}\right)^{1.22} \fallingdotseq 5.6\,\frac{\ell}{V_S} \qquad \ldots\ldots\ldots (6)$$

where V_S represents the velocity of S-wave in the ground. If we denote by $|X|$ and $|Y|$, the magnification factors at the peaks for the displacements of the center of gravity of the rigid body due to the translation and rotation in response to the ground motion, they are then given approximately by

$$|X| = 5.6\, a_0^{-1.57} \qquad \ldots\ldots\ldots (7)$$

and

$$|Y| = 3.4\, a_0^{-1.92} \qquad \ldots\ldots\ldots (8)$$

respectively, where

$$a_0 = \frac{2\pi r_0}{V_S T} \qquad \ldots\ldots\ldots (9)$$

denote the ratio of the length of the periphery of the base and the wave length L of S-wave in the ground.

While in the second case, a one-mass undamped system with a period shows maximum response

$$|Z| = 1.45\, S_0^{-1} a_0^{-3} \qquad \ldots\ldots\ldots (10)$$

$$S_0 = \frac{\rho_B}{\rho}\,\frac{\ell}{r_0} \qquad \ldots\ldots\ldots (11)$$

for the incident wave with a period

$$T = 0.75\, a_o^{-0.2} T_o \qquad \ldots\ldots\ldots (12)$$

in which ρ denotes the density of the subsoils and other notations being the same as in the above case 1). It may be added that the response maximum occurs when the period of the ground is a little longer than the natural period of the building T_o.

In a vibrating system with a finite damping, the response maximum is

$$V_{max} = \frac{1}{2h\sqrt{1-h^2}} \qquad \ldots\ldots\ldots (13)$$

times of the imposed ground motion. The finiteness of all of the $|X|$, $|Y|$, and $|Z|$, thus indicates that the dissipation of energy into the ground manifests a similar effect as the usual damping. The effective or equivalent damping constant in the above case 3) becomes as large as 7% of the critical when $a_o = 1$, and $S_o = 0.5$, increasing with these parameters. Thus from the formulae (7), (8), (10) and (13) the equivalent dampings are inversely proportional to T^n where n is about 1.5, 2, and 3 for $|X|$, $|Y|$, and $|Z|$ respectively. We can also perceive that the damping increases the larger the length of the periphery of the base of the building and the softer the ground, that is, the shorter the wave length of the S-wave in the ground.

Other cases in which a building undergoes a flexural or shearing vibration, or more general vibration, are now under study, in which we have seen no indication that any fact may be found which will negate the nature here described.

CONCLUSIONS AND THEIR BEARINGS TO EARTHQUAKE ENGINEERING

In the review of small amplitude vibrations of actual buildings in Japan, which are restricted in their height and with a lower limit of allowable design strength higher than in America, we could perceive that they are actually marked by their smaller height-to-width ratios and their shorter natural period. These high rigidity and form characteristics resulting from small height-to-width ratios, seem to facilitate rocking motions and shearing vibrations. These points are, in our opinion, contributive to the stability in a strong motion earthquake, not only of themselves but also through the increase of damping, and through the cushioning action provided by the underlying ground.

In fact, the damping constants of the actual buildings distribute between 3% to about 20%, increasing almost linearly with their natural frequencies. This characteristic dependence of the damping on the natural frequency was predicted by K. Suyehiro from the nature of building materials and proved later by K. Sezawa and us by the dissipation of energy into the ground. This may therefore be presumed to be established at least qualitatively. This, we think, is a fact which should not be casually overlooked from an engineering point of view, since there seems to be the possibility of a hidden clue to the approach to the important question of whether the rigid type construction historically adopted in Japan or the flexible type of structure developed in the United States

of America is better suited to aseismic purposes.

In view of the paramount importance of the last problem, the writers beg to be permitted to touch upon it from their present point of view. One of the most powerful reasons supporting the American practice is perhaps the fact revealed by the earthquake spectrum, that the response base shear of a building decreases almost inversely with the natural period of the building. But, the writers believe that the effect of the damping must be taken into consideration at the same time, because it is a function of the period of a building, and indeed from our observations its effect is to cancel the advantage of the long-period building, the damping constant being at least inversely proportional to the natural period. Now, if there exists a coherent train of periodic motion in the emergent wave and it lasts several times the period, it is usually sufficient to establish a stationary state in an ordinarily damped building. The seismogram of the great Kanto earthquake at Hongo indicated that this was the case. It is suggested also that large earthquakes with magnitudes over 8 in the Richter Gutenberg scale may exhibit such characteristics. In such cases a building with finite damping and having the same natural period as the coherent wave vibrates with amplitude V_{max} times, being given by (13) and reducing to $1/2h$, of the ground motion, in ordinary cases. If, on the other hand, the ground motion does not contain such a coherent train as in ordinary strong motion earthquakes, the response is, according to the mean of 36 damped earthquake spectra as worked out by Alford, Housner and Martel are concerned, proportional to $h^{-0.4}$ in the above range of the damping h. According to the characteristic relations of h and T, the responses in these two cases are proportional to T and $T^{0.4}$ respectively. Thus if we combine this effect of damping to the characteristics of the earthquake spectrum, to be proportional to T^{-1} for T over 0.25 sec, the responding acceleration or the base shear of a building becomes proportional to T^{0} or $T^{-0.6}$ respectively. If we are to compare the stability of two buildings with the same demensions but of different periods, by the amount of base shear, the American and the Japanese practices are on a par, or the American practice may be superior.

But on the other hand, if we consider that the destruction is caused by the deficiency of the fibre strength against the bending moment in the flexural vibration, or the shearing stress in the shearing vibration, the stability relation with the period of the building will be altered from the above conclusion, because both of the bending moment and the shearing stress are directly proportional to the amplitude of the displacement and inversely proportional to the wave lengths of the waves in the building. As is proved by Housner (24), the response displacement spectrum of a building to a strong earthquake is proportional to T, and if the effect of damping above mentioned is taken into consideration, the response displacement will be proportional to T^{2} or $T^{1.4}$ respectively. Therefore the bending moment or the shearing stress in the building becomes proportional to T or $T^{0.4}$ corresponding to coherent or incoherent earthquake motions. In this sense the American practice is not, if we are not mistaken, guaranteed to be superior. Anyhow we shall be very glad if our present study is made a stepping stone to any fresh investigations of the savants on this problem.

Lastly we should like to add that the vibration tests could be used more extensively, not only for the theoretical verifications for scientific and technical progress, but also for the welfare of the people in detecting instability of actual buildings. Though we did not touch on the quantitative analysis of the results of vibration tests for the above purposes, the magnitude alone of the building vibrations caused by a prescribed driving force as shown in Fig. 1 may be used for such a purpose.

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FIGURE CAPTIONS

Fig. 1. Deflection curves of Japanese buildings (fundamental mode).

Fig. 2. Deflection curves along vertical axis, base, floor and roof of the Fuse Ninth Middle School.

Fig. 3. Deflection curves of the Daiichi Sōgo Building. Black circles denote those for longitudinal vibration while hollow circles denote the same for transverse vibration. (After T. Naito et al.)

Fig. 4. Deflection curves of the Matsuzakaya Department Store, Ginza, Tokyo, due to the longitudinal vibrations (black circles) and the transverse vibrations (hollow circles). Large circles denote the fundamental modes, while the small circles denote the second harmonics. (After T. Naito and N. Nasu.)

Fig. 5. Fundamental period of Japanese building in relation to the height and the depth. Thick large circles denote steel frame structures, thin large circles denote fero-concrete buildings built in the last ten years, while small circles denote the same type of buildings before 1945. Small black spots denote the buildings burnt by fires in the war. Circles with a cross denote buildings which were later damaged by the Kanto earthquake, while the same with black quadrants denote the same buildings in their damaged state.

Fig. 6. Relation between damping constant h in percent of critical with the period T of the building. Large double circles denote steel frame structures while others are feroconcrete buildings. Black circles denote the burnt structures, while small circles with inner dots denote the monolithic pillarless feroconcrete buildings.

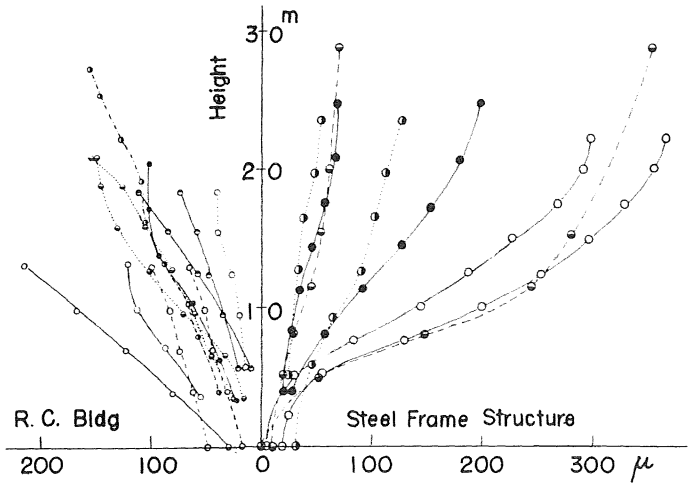

Fig. 1

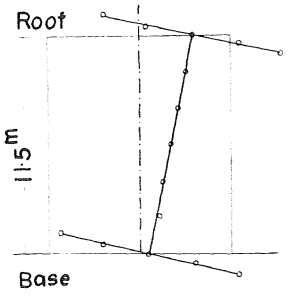

Fig. 2

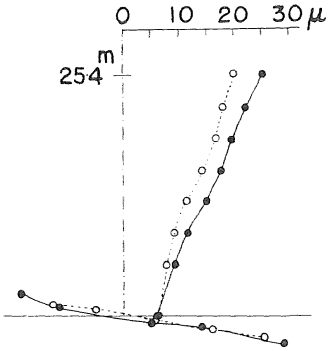

Fig. 3

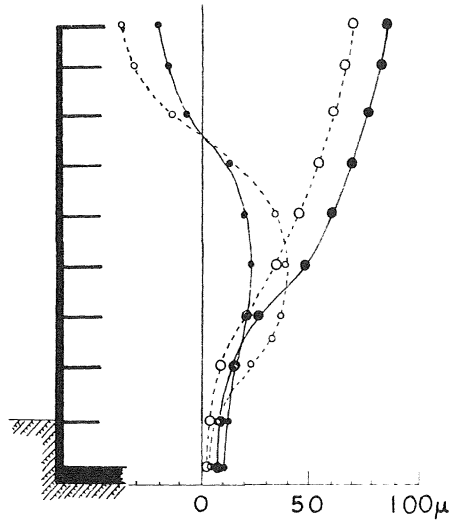

Fig. 4

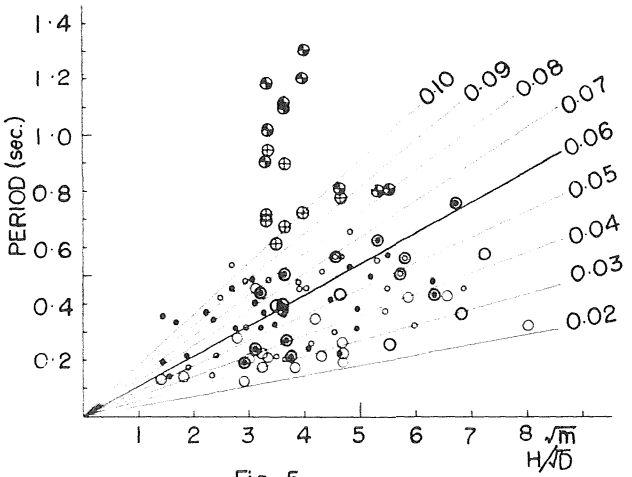

Fig. 5

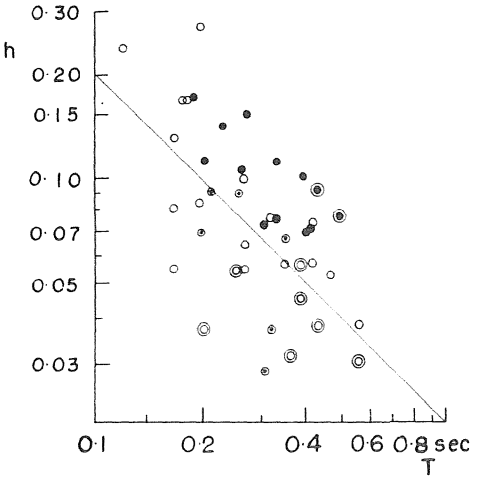

Fig. 6