DAMPING COEFFICIENTS OF STRUCTURAL VIBRATION RELATED TO SUBSOIL CONDITIONS

by
Hiroyoshi KOBAYASHI[I]

SYNOPSIS

It is well known that the effects of modal damping are remarkable for the earthquake structural response against not elasto-plastic vibration but also elastic vibration. The author investigated the most effective factor of damping of structure by reviewing the observed data, especially using the microtremors. The author selected two characteristics of subsoil condition as the most relevant factors for decide the damping coefficients of structure, one is the kind of ground and the other is the predominant period of ground which supporting the structures. And shows the effects of subsoil conditions for the value of damping coefficients of structure.

NOMENCLEATURE

T : Period of structure
T_s : Period of s-th mode
T_g : Predominant period of ground
TpmN : Predominant period of ground (see section 6)
h : Damping coefficient (ratio of critical damping)
h_s : Damping coefficient of s-th mode
$m\ddot{y}$: Inertia force
$C\dot{y}$: Viscous damping
$F(y)$: Elasto-plastic function
$\ddot{X}$: Acceleration of ground
y : Deformation

INTRODUCTION

Many studies which have been made on the structural dampings can be classified as following;

(1) The dissipation theory of shear wave propagation through a soil-structure system.
(2) Viscous damping due to internal friction of structural members.
(3) Viscous resistance of ambient air.
(4) Damping effects due to the relative movement between the foundation and surrounding soil.

On the other hand, many surveys and experiments which took into account the effects mentioned above were carried out, and a great deal of data have been accumulated. But these data can not illustrate the mechanisum of

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[I] Professor, Tokyo Institute of Technology, Dr. of Eng.

total damping system of structure so clear.

The magnitude of deflection of structure or strain of soil during the earthquake or microtremor is an important factor for determining the value of damping constants. Damping characteristics of a structure is illustrated as viscous damping in the elastic range of stress-deflection characteristics and hysteretic damping in the plastic range. But modal damping, which is used in the dynamic analysis of structures during earthquakes, is treated as viscous damping. The equation of elasto-plastic vibration of one mass system is shown in equation (1).

$$m\ddot{y} + C\dot{y} + F(y) = -m\ddot{X} \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

In this equation, the damping effects of $C\dot{y}$ is treated as viscous damping and the damping effects of energy loss of $F(y)$ is defined as hysteretic damping. Then the author investigated the most effective factor for damping of structure by reviewing the observed data.

1. RELATION BETWEEN DAMPING COEFFICIENT AND NATURAL PERIOD OF BUILDINGS

About the vibration of actual buildings, many tests and observations during earthquakes were carried out and many papers about these results were presented. The author has reviewed these results and shows a relation between the period and damping coefficient about the fundamental mode of vibration of buildings in Fig.1. The data including the results of three kinds of structure, steel structure, reinforced concrete structure and steel-reinforced concrete structure. But he has not found the difference in these relations due to the kind of structure. The damping coefficient h is inversely proportional to the fundamental period T of structure, and this relation is mentioned as following;

$$h \times T = \text{constant} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

However, the value of h.T are fluctuated in a wide range, and he can found the upper limit of h.T-value at 0.05. The lower limit of h.T-value is not so clear and it is possible to take a small value as 20 to 30 percent of the upper limit, if it is the case of the same natural period.

It is considered that the fluctuation of h.T-value is caused by the strain level of vibration. In sometimes structures reach to the plastic range and the fluctuation includes the effects of hysteretic damping. In Fig.2, he shows the relation between the h.T-value and its top deformation against the basement during the measurement, and this figure means the h.T-value is constant value in these strain level. Then he does not found the effects of hysteretic damping and these results were considerable as the effects of visco-elastic vibration problem.

Then next in Fig.3, the author shows a relation between the period and damping coefficient about the higher mode vibration of actual structures. According to Fig.3, s-th mode damping coefficient is indicated as equation (3);

$$h_s = T_s^{-n}, \qquad n = 0.5 \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

In the case of damping due to internal friction of structure, the value of n must be equal to 1.0. But in this case is not so, then he concluded that the matter is depended the characteristics of ground and soil-structure interaction problem.

2. MEASUREMENT OF DAMPING COEFFICIENTS BY MICROTREMORS

Some papers reported that, the damping value of structure during microtremor are very close to the damping values during earthquake whose maximum acceleration is 100 gals, and experimental results of damping coefficient are rather increase only few percent depending on the increment of deformation of structure.(1) However, the mean value of the h.T-values which are caused by same strain level is not varied through the different strain level, as shown in Fig.2. So it is adequate that the whole data of this paper are treated as the problem of elastic deformation of structure and the phenomena of viscous damping. And the data of damping decided by measured microtremors show the equivalent value of the case of during earthquake, whose maximum acceleration is 100 gals or less than 100 gals.

Then in this paper, the investigation about the effects of subsoil conditions are carried out by using the data of microtremor. In the computation of damping coefficients by the microtremor which observed at the top of structure, the author has used the method of power spectrum density of a duration limited by the Hamming type lag window.

3. EFFECTS OF DAMPING IN THE ELASTIC RANGE OF STRUCTURE

It is well known that the effects of modal damping are remarkable for the earthquake structural response against not only elasto-plastic vibration but also elastic vibration.(2) As the results of these studies, if it is a case of plastic deformation is large and hysteretic damping is effective for earthquake response, viscous damping has remarkable effects for the increase of structural response in the elastic range. Then the author points out that the value of damping coefficient must be determinded carefully, in the case of the damping phenomena devided into the viscous damping in elastic range and hysteretic damping in plastic deformation. And also it is an important problem, that the mechanisum and magnitude of viscous damping should be investigated as soon as possible, because the hysteretic damping has been taken into the computation of structural response and the damping effects due to lost energy of hysteretic characteristics has been estimated in the antiseismic analyses of present structural design, though it is insufficiently.

4. RELATION BETWEEN THE KIND OF SOIL AND DAMPING COEFFICIENT OF BUILDING

The viscous damping characteristics of building are close related to the nature of subsoil, which supporting the buildings, as mentioned above. The author picked up buildings, which have same conditions, kind of structure and magnitude of floor area, and different subsoil condition. Then he investigated the effects of ground for the structural dampings. For example, he chose 37 school buildings of Kawasaki City, whose structure are three storied concrete construction. The distribution of chosen school buildings is shown in Fig.4. About the subsoil conditions of this area, detailed field suvey reports have been presented in the separate papers.(3)(4) Furthermore K.Kanai has decided the kinds of ground by his method using the microtremors in same area.(5)

The depth of N-value=50, that is decided by boring tests, is often used to the scale of ground nature, which indicates the hardness. The author shows a relation between the h.T-value and the depth of N-value=50 in Fig.5. This figure shows a trend of increase of h.T-value depending to the increase of the depth of soft soil, but it is not so clear. On the other hand, the kinds of ground are defined in Japanese Building Code, that is shown in Appendix of this paper, and classified into four ranks depending to the nature of the soil upon which a structure is founded. So the author rearrenged these data by this category and the relation is shown in Fig.6. This figure shows a rather clear relation between the h.T-value and the kind of ground. And the h.T-values are defined in the area of Kind II as 0.005-0.02, Kind III as 0.008-0.04 and Kind IV as 0.02-0.05 approximatelly.

These results show that the subsoil effects for viscous damping of structures are as following;
(a) Structures are confined by surrounding soil effectively, but damping characteristics show inverse trends, then the softer ground shows a larger h.T-value for viscous damping.
(b) The definition about the kind of ground is able to apply for the determination of magnitude of viscous damping.

5. FLUCTUATION OF DAMPING h.T-VALUE

Damping characteristics are varied depending on the ground characteristics as mentioned above, then the author investigated the method by numerical discription of subsoil effects. The nature of damping is discussed in this paper as the h.T-value, that the product of viscous damping coefficient h and natural period T of buildings, but if the rigidity of supporting soil is changed, the natural period is also changed. Relations between the predominant period of ground and natural period of buildings, and between the natural period and damping coefficient of building are shown in Fig.7 about the three storied reinforced concrete structures. This figure shows the effects of subsoil more clearly. The buildings, which are shown in Fig.7, are as same as previous section and have a few difference in supper structure themselves. As shown in figure, the period of building increase depending on the increment of ground period and the damping value increase depending on the increment of building period, so the building, that is supported by soft ground, has a large damping coefficient. This facts is very important problem for the viscous damping of the structure and the fluctuation of the h.T-value is most influenced by this matter.

6. DETERMINATION OF DAMPING COEFFICIENTS BY THE PREDOMINANT PERIOD OF GROUND

The fourier spectrum of surface movement of soft ground is very complicated and many peaks appear on the spectrum. Then it is difficult to determine the predominant period. In the case of microtremor, it has same problem also. The period of the most intensive peak among the peaks of spectrum is meant as representative predominant period of ground. But in this section the predominant period is defined under the consideration of rather long period who has rather intensive one, that is means to consider the subsoil structure which has a rather long period. Now it is called predominant period TpmN in this paper, that is the longest period among the periods of peak which has intensity of above N percent of most intensive peak value of power spectrum, and the spectrum is made by the microtremor at ground surface. See Fig.8.

The predominant period is useful for a scale of confinement of surrounding soil as mentioned above. For investigate the effective soil volum, the correlations between h.T-value and TpmN-value are considered by changing the value of N. The relation of previous section is limited to the same conditions for structures, however, the fluctuation of h.T-value is not depended for the condition of supper structure. So the author plotted the relation between h.T-value and predominant period TpmN about whole data which have different supper structure. In Fig.9 shows a case of N is 100, and in Figs.10, 11 and 12 shows each N is 80, 50 and 20. The case of value of N is 50, shows a best correlation among the figures, and the longest period Tpm50 of ground is 1.2 sec., in this case. This results mean that the wide and deep soil related to the viscous damping of the structure.

CONCLUSION

It is clear that the subsoil conditions are most effective for the fluctuation of the h.T-value mentioned above. So the author selected two characteristics of subsoil condition as the most relevant factors for the fluctuation:

(a) KIND OF SUBSOIL According to the Japanese Building Code, is classified into four ranks depending on the nature of the soil upon which a structure is founded. As shown in Fig.6, the h.T-value depends on the hardness of subsoil. Then it is possible to take a large h.T-value for a structure on the soft ground, and a small value for the case of hard ground. This conclusion is reached under the consideration of natural period of ground, that is given longer value in the case of soft ground.

(b) PREDOMINANT PERIOD OF GROUND in the case of soft groud, many peaks appear on the fourier spectrum of microtremors, that is observed on the ground surface, and then several predominant periods are obtained. Fig.11 shows a relation between the h.T-value and the longest predominant period among the peaks of power spectrum whose intensities are more than 50 percent of the intensity of the maximum peak of spectrum. The ratio of 50 percent is chosen as a best one for making good correlation by trial and error. This means that the damping depends on the predominant period, that is influenced by the soil having a certain thickness, and the thickness of soil is defined by the interaction between building structure and subsoil. In the case of Tokyo, alluvium and diluvium are included in this subsoil, and the damping of structure has a close relation not only with shallow soft soil layer but also with deep layer.

ACKNOWLEDGMENT

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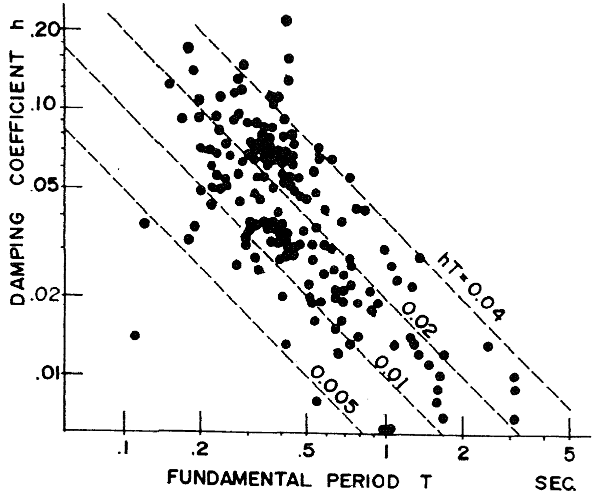

FIG. 1 RELATION BETWEEN DAMPING COEFFICIENT AND FUNDAMENTAL PERIOD OF BUILDING

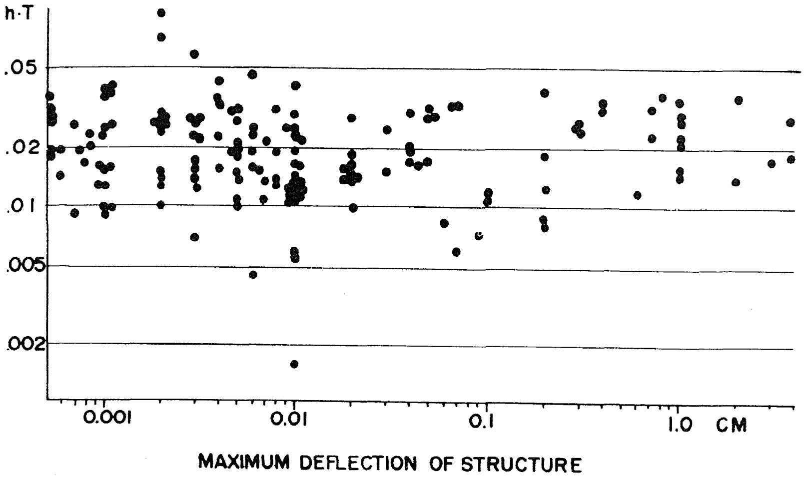

FIG. 2 RELATION BETWEEN DAMPING h·T VALUE AND STRAIN LEVEL OF EXPERIMENT

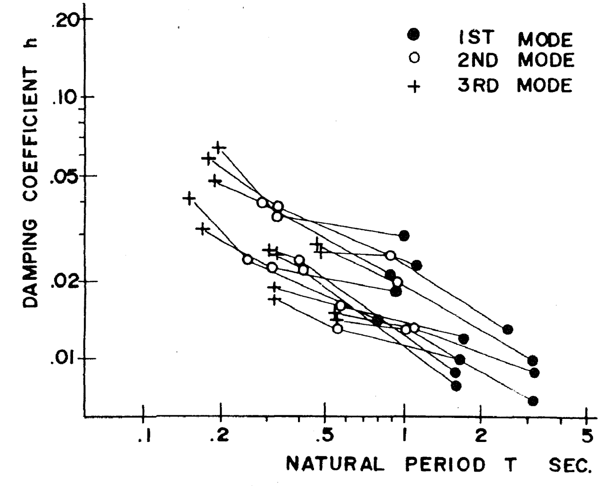

FIG. 3 DAMPING COEFFICIENTS OF HIGHER MODE

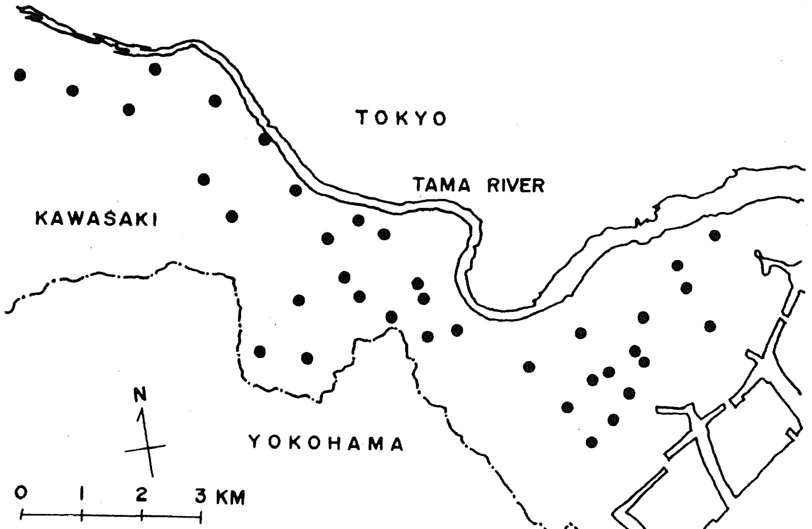

FIG. 4

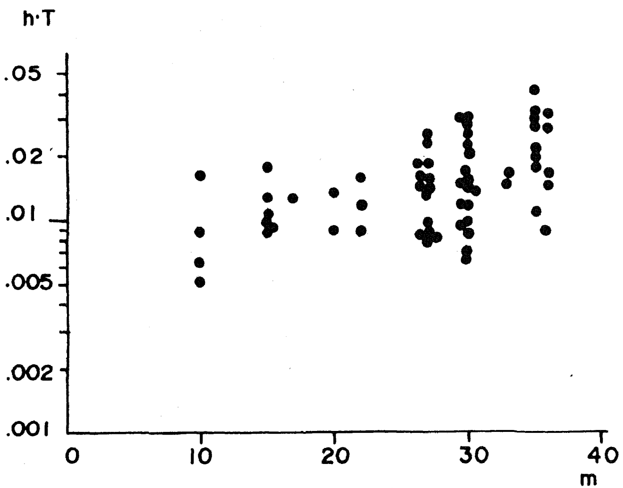

FIG. 5 EFFECT OF THICKNESS OF SOFT GROUND

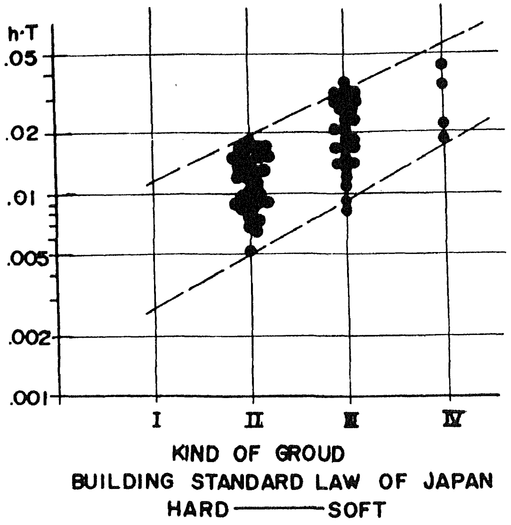

FIG. 6

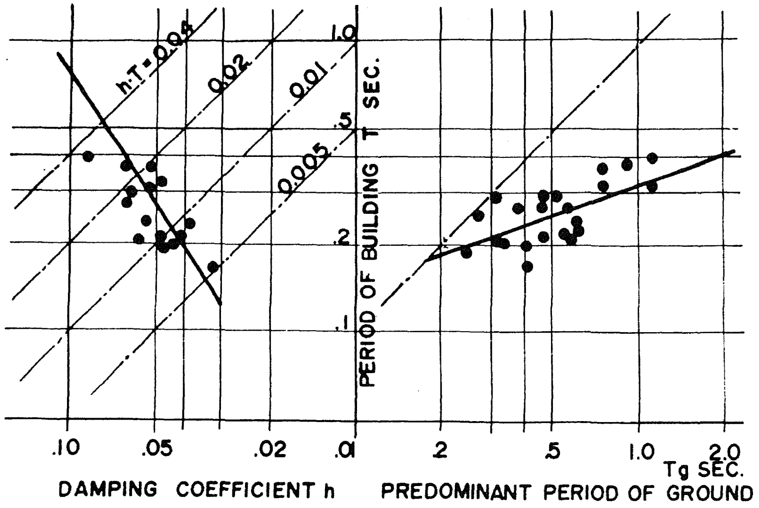

FIG. 7 DYNAMIC PROPERTIES DEPEND ON GROUND CONDITIONS

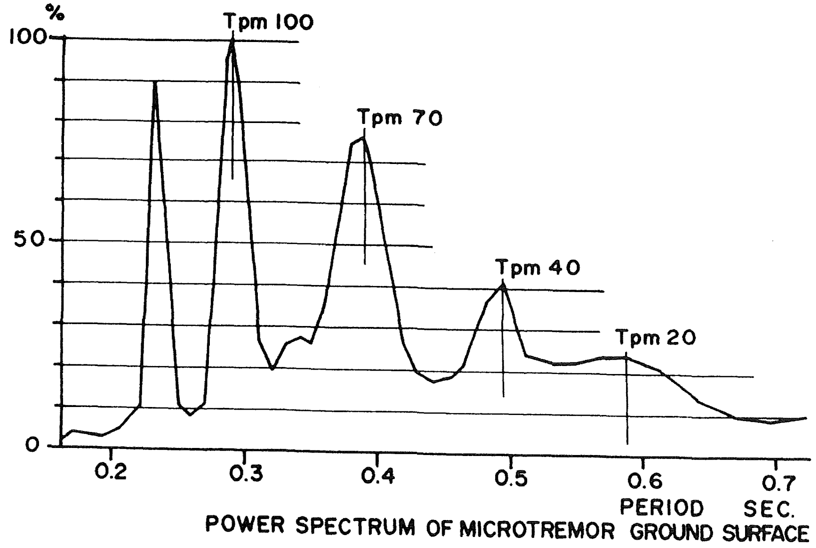

FIG. 8 DEFINITION OF PREDOMINANT PERIOD Tpm N

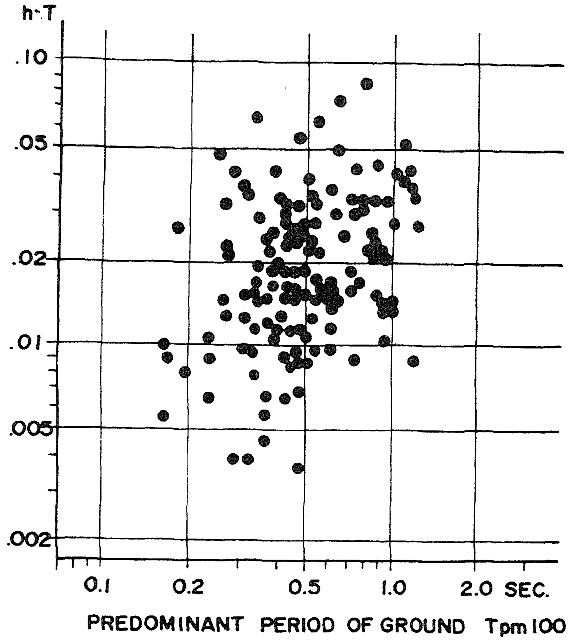

FIG. 9

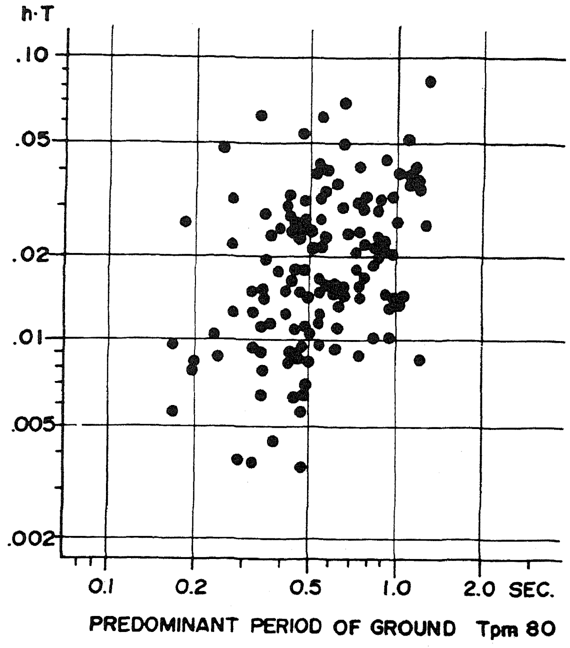

FIG. 10

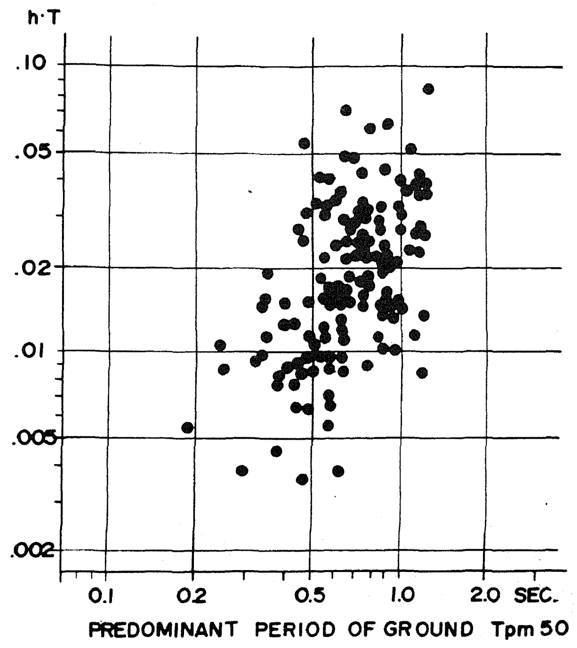

FIG. 11

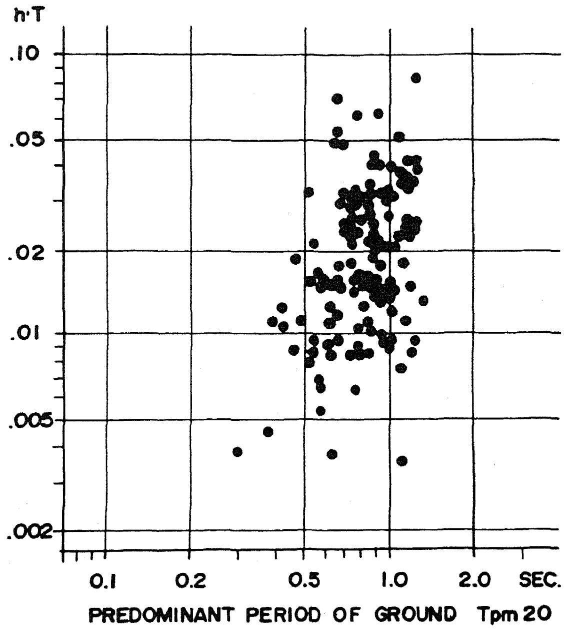

FIG. 12

APPENDIX KIND OF GROUND

Kind of ground is defined in Japan as following;
(from Ministry of Construction Notification NO. 1074, July 25, 1952)

Kind I : Ground consisting of rock, hard sandy gravel, etc. classified as Tertiary or older strata over a considerable area around the structure.

Kind II : Ground consisting of sandy gravel, sandy hard clay, loam, etc. classified as diluvial or gravelly alluvium, about 5 meters or more in thickness, over a considerable area around the structure.

Kind III : Ground other than those mentioned in Kind I, II and IV.

Kind IV : The ground shall be designated as Kind IV when it falls in one of the following categories;
a) Alluvium consisting of soft delta deposits, topsoil, mud or the like (including heaping up, if any), whose depth is about 30 meters or more.
b) Land obtained by reclamation of a mash, muddy sea bottom, etc., of which the depth of the reclaimed ground is about 3 meters or more and where 30 years have not yet elapsed since the time of reclamation.