CHARACTERISTICS OF SURFACE GROUND MOTIONS CONSIDERING THE VARIOUS PROPERTY COMBINATIONS OF SUBSOILS AND EARTHQUAKES

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SUMMARY

In this paper, the input earthquake motions with different intensity levels and frequency contents are generated at first. Next, a number of soil profiles are chosen so that the fundamental periods of soil deposits are uniformly distributed and they represent the most types of soil conditions. The surface motions of soil deposits, when subjected to the earthquake motions, are computed, considering the nonlinear behavior of soils. The characteristics of surface motions, such as the amplification ratios of the acceleration, the velocity, the spectral values and the reduction of stiffnesses of soil layers, are discussed.

INTRODUCTION

It is well-known that the subsoil conditions and damage features during earthquakes are closely correlated. The severe damage was generally caused at the sites of alluvial soils. During the Miyagi-ken-oki earthquake of June 12, 1978, the similar damage features have been observed, i.e., severely damaged reinforced concrete and steel structures and wooden houses were concentrated in the soft soil plain. On the other hand, damage to structures in the terrace at the central part was quite slight.

The characteristics of surface motions of soil layers during an earthquake depends on the dynamic properties of soils and the intensity level of the earthquake motion.

EARTHQUAKE GROUND MOTIONS AT EXPOSED BASE LAYERS

Earthquake ground motions for design purposes are often expressed in the forms of the design response spectra. In Ref. 1, the design spectra on hard rocks are proposed in terms of the earthquake magnitudes and the epicentral distances.

In this study, the earthquake ground motions of five types, i.e., earthquake magnitudes (M) of 6, 7 and 8 with the identical epicentral distances (Δ) of 50 kilometers, M of 6.5 with Δ of 18 kilometers and M of 7.5 with Δ of 50 kilometers, are generated by applying the above-mentioned proposed design spectra. These spectra are shown in Fig. 1. The spectra are specified with the intention of examining the effects of the intensity levels and frequency contents of the earthquake motions upon the surface responses of soil deposits.

As is shown in Fig. 1, the frequency contents of the spectra for motions

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of M's of 6, 7 and 8 are nearly same, except for their intensity levels. While the intensity levels of the spectra for motions of M's of 6.5 and 7.5 with different epicentral distances are nearly same, except for their frequency contents.

Generation of Earthquake Accelerograms

The motions compatible with those design spectra are generated in accordance with the specifications indicated in Ref. 2, namely,

(1) The periods and the spectral values which determine the design spectra are shown in Table 1.

(2) Duration time of each motion is determined by the following equation,

$$T_d = 10^{0.31M - 0.774}$$

where T_d : magnitude-dependent duration time in second, beyond which amplitudes do not exceed 1/10 of the maximum amplitude

M : earthquake magnitude

(3) The nonstationarity of the motion is given by the envelope curve as shown in Fig. 2. The envelope curve is represented by a quadratic $(t/T_b)^2$ in the range of t=0 to T_b and by an exponential curve $\exp[-a(t-T_c)]$ (a : constant) in the range of $t=T_c$ to T_d. The times, T_b and T_c for motions concerned are also indicated in Table 1.

The earthquake accelerograms thus generated are shown in Fig. 3 and the maximum amplitudes of the motions are summarized in Table 2.

SOIL PROFILES REPRESENTING VARIOUS KINDS OF SOIL CONDITIONS

Soil conditions are generally evaluated geologically, topographically or mechanically. In this study, it is assumed that soil deposits are horizontally layered and earthquake motions propagate only vertically. Therefore, the effects of topographical irregularities of soil deposits upon the surface responses are not taken into account.

Thirty-two soil profiles are chosen so that the fundamental periods of those soil deposits are uniformly distributed in the range of 0.1 to 1.5 sec. Configuration of each soil profile is shown in Fig. 4 in the descending order of the fundamental periods.

Soil profiles utilized herein are mostly of the Quarternary, thicknesses of which are 20 to 50 meters. Those of smaller thicknesses are mostly of diluvial soils. In Fig. 4, the layers with horizontal broken stripe are of soil types of clayey soils. Similarly, the layers without any symbols are of soil types of sandy soils and the layers with vertical solid stripe are of soil types of gravelly sand or gravel. The numbers affixed to the layers of each soil profile in Fig. 4 indicate the N-values obtained by the standard penetration tests. Those N-values are used to evaluate the initial shear moduli by the following empirical equation. (Ref. 3)

$$G_0 = 1200\,N^{0.8}$$

where G_0 : initial shear modulus

N : N-value obtained by the standard penetration test

COMPUTATION OF SURFACE GROUND MOTIONS

The earthquake responses of soil layers are computed by the direct integration of equations of motion by employing the nonlinear stress-strain relationship proposed in Ref. 4. The skeleton curve is expressed as,

$$\gamma = \frac{\tau}{G_0} \cdot \left(1 + a \left| \frac{\tau}{S_u} \right|^b \right)$$

where γ : shear strain, τ : shear stress,
G_0 : initial shear modulus, S_u : shear strength

The coefficients a and b depend on soil types, such as clay or sand. The damping of Rayleigh type other than the above-mentioned hysteretic type is additionally given, assuming 2 percent both for the first and the second modes of the analytical model of soil deposit.

CHARACTERISTICS OF SURFACE GROUND MOTIONS

The amplification ratios of maximum response acceleration and velocity at the ground surface to the maximum acceleration and velocity of the input motion are shown in Fig. 5 and Fig. 6, respectively, with respect to the fundamental period of soil deposit. The ratios for acceleration are generally decreased as the intensity levels of the input motions become larger and the fundamental periods of soil deposits become longer. The ratios for velocity are, on the other hand, increased as the fundamental periods become longer. The effects of the intensity levels upon the ratios of velocity are not clear.

The ratios for acceleration for similar intensity levels are shown in Fig. 7. In most cases of soil conditions applied herein, the ratios for the input motion of M=7.5 are slightly larger.

The stiffness of soil deposit, represented by the shear modulus, are reduced, when the earthquake motion is being subjected. The fundamental period of soil deposit is related with the shear moduli of soil layers, e.g., the fundamental period is inversely proportional to the square root of the shear modulus, when the soil is single-layered.

The stiffness reduction ratio due to an earthquake motion is, therefore, defined herein as the reciprocal of the square of elongation rate of the fundamental period of soil deposit.

The stiffness reduction ratio shown in Fig.8 is computed with the period for initial shear moduli and the period for the minimum shear moduli of soil layers induced in the duration time of the input motion.

From Fig.8, it is seen that stiffness reduction ratio is decreased as the intensity level of the input motion becomes large and the fundamental period of soil deposit are longer. In addition, the fundamental periods of soil deposits are elongated by 1.5 to 2.0 times compared with the initial values, when the input motion of M=8 is subjected.

Spectral Ratios and Spectral Intensity Ratios

Soil profiles shown in Fig. 4 are classified according to the fundamental periods for initial shear moduli as,

Type of Soil Condition	Period Range (sec)
(1)	~ 0.40
(2)	0.40 ~ 0.60
(3)	0.60 ~ 0.80
(4)	0.80 ~

As is shown in Fig. 5 to Fig. 8, responses at the ground surface are greatly influenced by the dynamic properties of soil layers. Those classifications are made in order to clarify the effects of soil conditions upon the surface responses. Two kinds of Spectral Intensities (SI) are herewith defined, i.e., the area of the acceleration response spectrum of 5 percent damping in the period range of 0.1 to 0.5 seconds, SI(0.1,0.5), and that in the period range of 0.5 to 1.0 seconds, SI(0.5,1.0). In Fig. 9, the ratios of SI(0.1,0.5) to those for the surface motions for the motion of M=6 are shown. The broken line indicates the identical relationships for the input motions. In Fig. 10, the relationships in case of SI(0.5,1.0) are shown. The increasing rate of the Spectral Intensity ratios for the shorter period range are reduced, as the magnitude of the input motion, i.e., intensity levels of the input motions, become large, especially in the case of the soil conditions of longer fundamental period, because the higher frequency contents of the surface motions are decreased due to the elongation of the fundamental periods. The reductions of the increasing rate of the Spectral Intensity ratio for longer period range are not clear in this case.

The ratios of acceleration response spectra for the surface motions to those of the input motions at the base layers, representing the soil conditions classified as (1) to (4) are shown in Fig. 11 to Fig. 14.

In Fig. 15 to Fig. 18, the ratios of those ratios to those for the input motion of M=6. The differences of the ratios of response spectra of the surface motions are not so large in the case of soil condition type (1), in spite of the differences of the intensity levels of the input motions. As the fundamental periods of soil deposits become longer, however, those spectral ratios for larger intensity levels decrease in the shorter range of periods.

CONCLUSIONS

In this paper, the surface motions of some kinds of soil conditions due to a number of earthquake motions with different intensity levels and frequency contents were investigated with respect to the amplification ratios of maximum amplitudes, spectral intensities and spectral ratios. It was shown that the amplification ratios of spectral values of the surface motions to those of the input motions would change according to the changes of the intensity levels of the input motions and the fundamental periods of soil deposits.

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Table 1 Response Spectra at Control Periods and Duration (h=0.05) Time (T_d) and Time Parameters for Envelope Curves

M	Δ(km)	PERIOD(sec)/ACC(gal)					T_d(sec)	T_b(sec)	T_c(sec)
8	50	0.02 279	0.14 963	0.32 969	0.68 458	2.00 85	50.82	4.06	23.38
7	50	0.02 70	0.13 240	0.33 241	0.81 99	2.00 28	24.90	2.98	12.45
6	50	0.02 18	0.10 70	0.32 70	0.69 32	2.00 6.5	12.20	1.96	6.58
6.5	18	0.02 145	0.11 471	0.25 458	0.59 193	2.00 25	17.42	2.44	9.06
7.5	50	0.02 144	0.14 494	0.32 494	0.76 206	2.00 48	35.56	3.56	17.06

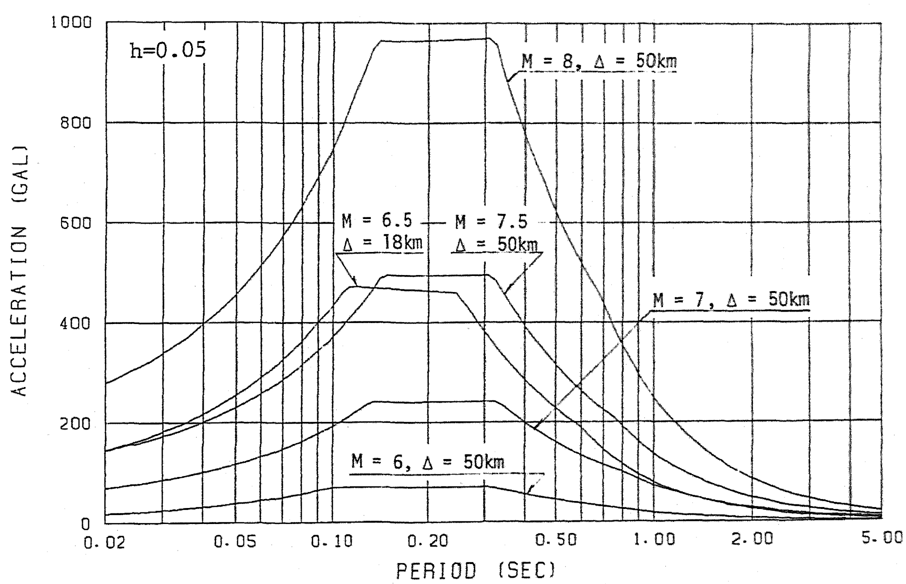


Fig. 1 Design Response Spectra Used in This Study

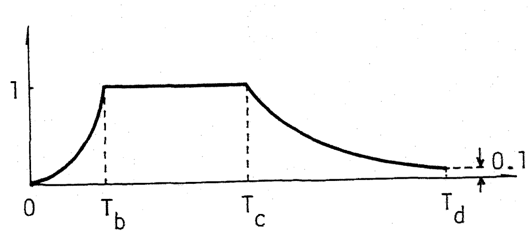


Fig. 2 Envelope Curve

Table 2 Maximum Amplitudes of Simulated Motions

M	Δ (km)	Max. Amplitudes Acc.(gal)	Vel.(kine)
8	50	361.1	21.5
7	50	93.8	7.9
6	50	25.8	1.9
6.5	18	167.6	7.8
7.5	50	178.7	12.4

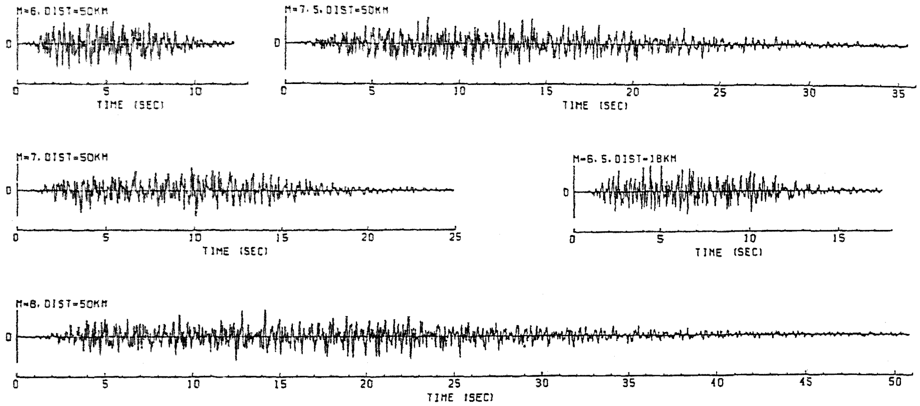


Fig. 3 Simulated Earthquake Accelerograms, Response Spectra of Which Are Compatible with Design Spectra shown in Fig. 1

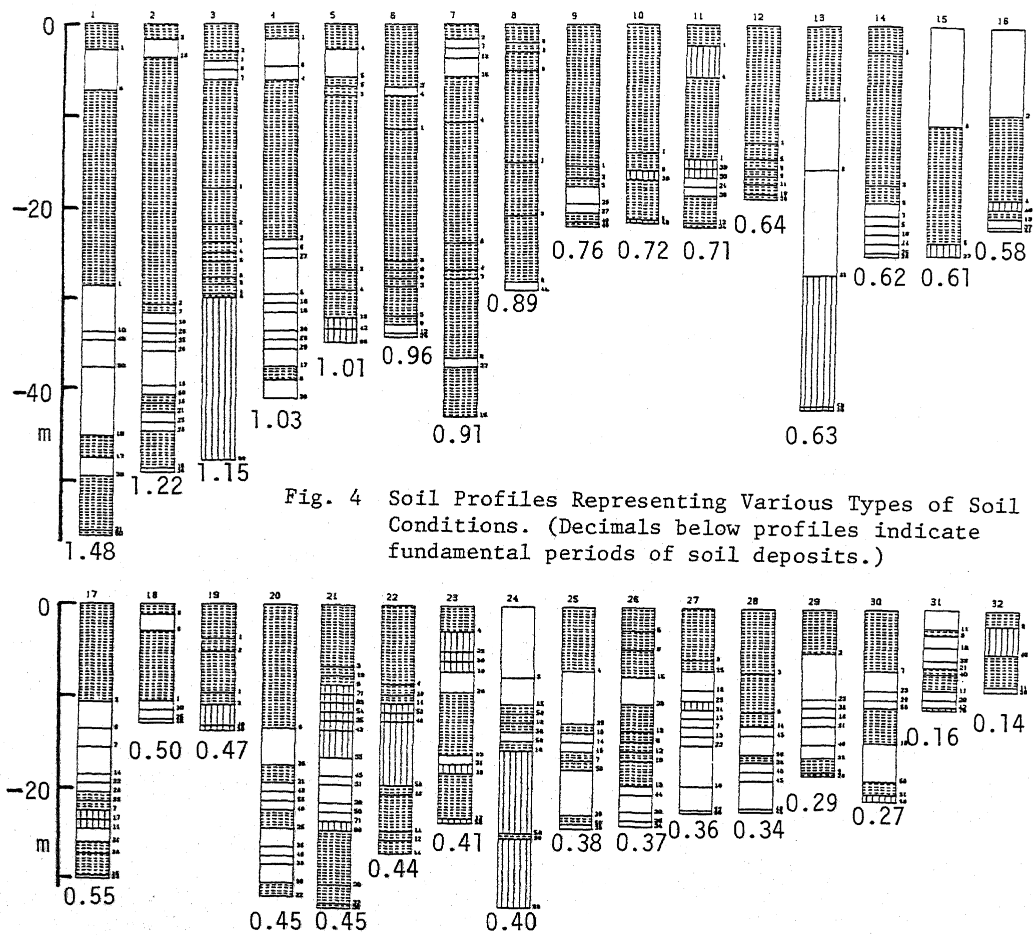


Fig. 4 Soil Profiles Representing Various Types of Soil Conditions. (Decimals below profiles indicate fundamental periods of soil deposits.)

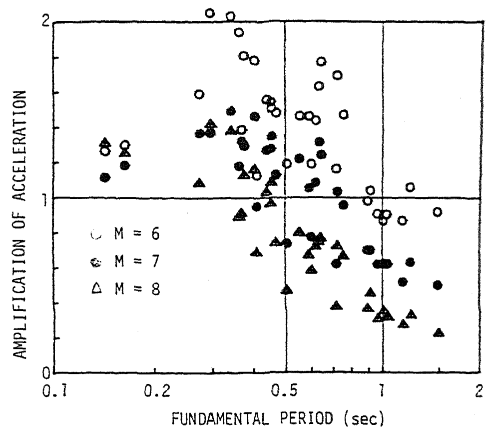


Fig. 5 Ratios of Max. Acc. between Ground Surface and Exposed Base

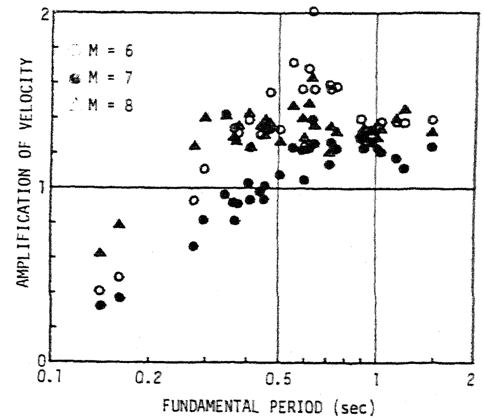


Fig. 6 Ratios of Max. Vel. between Ground Surface and Exposed Base

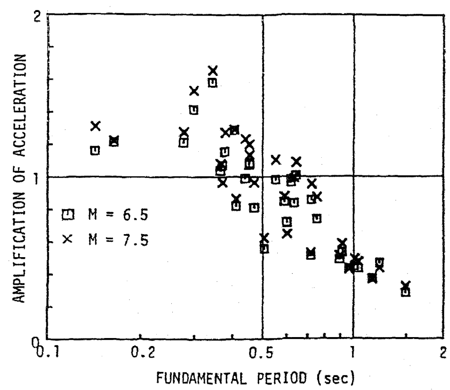


Fig. 7 Ratios of Max. Acc. between Ground Surface and Exposed Base

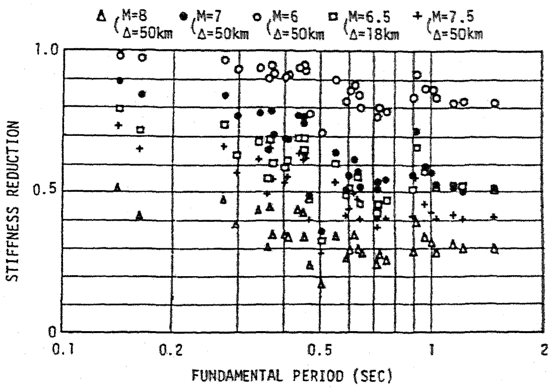


Fig. 8 Stiffness Reduction Ratios for Five Types of Input Motions

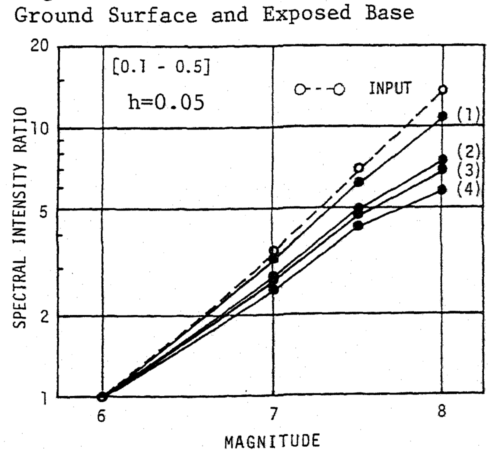


Fig. 9 Ratios of Spectral Intensities to Those for motion of M=6

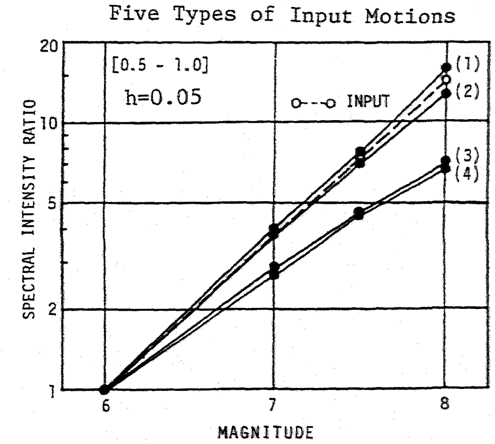


Fig. 10 Ratios of Spectral Intensities to Those for motion of M=6

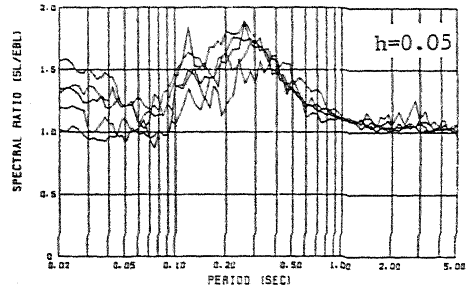


Fig. 11 Ratios of Response Spectra to Those of Input Motions for Soil Profile No. 30 in Fig.4 classified as Type (1)

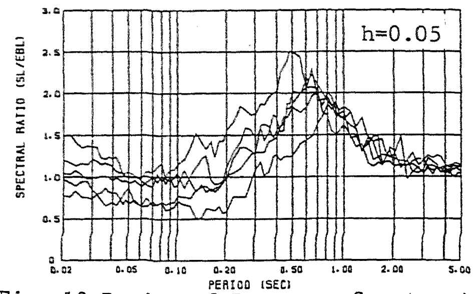


Fig. 12 Ratios of Response Spectra to Those of Input Motions for Soil Profile No. 17 in Fig.4 classified as Type (2)

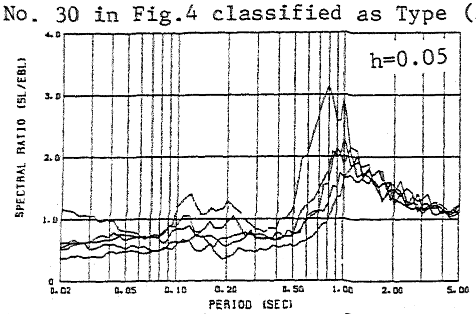


Fig. 13 Ratios of Response Spectra to Those of Input Motions for Soil Profile No. 11 in Fig.4 classified as Type (3)

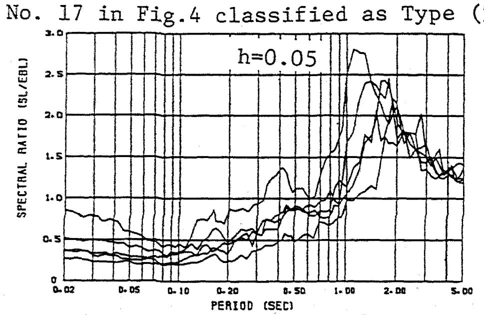


Fig. 14 Ratios of Response Spectra to Those of Input Motions for Soil Profile No. 3 in Fig.4 classified as Type (4)

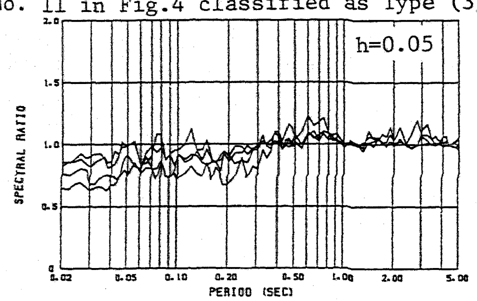


Fig. 15 Ratios of Spectral Ratios to Those for Motion of M=6 in Fig. 11

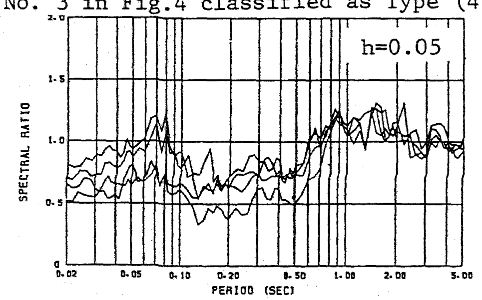


Fig. 16 Ratios of Spectral Ratios to Those for Motion of M=6 in Fig. 12

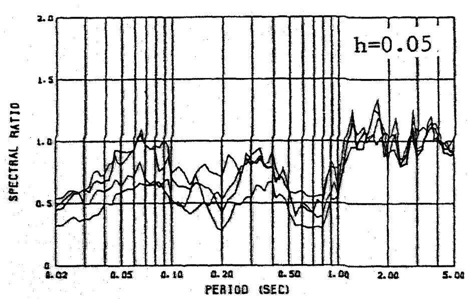
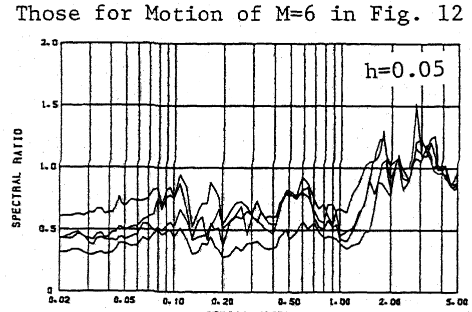


Fig. 17 Ratios of Spectral Ratios to Those for Motion of M=6 in Fig. 13



Fig, 18 Ratios of Spectral Ratios to Those for Motion of M=6 in Fig. 14