Paper No. 1279. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

1 DIMENSIONAL SCATTERING MODEL FOR HORIZONTAL SOIL LAYERS

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ABSTRACT

When layer boundary is uneven, it is supposed that the wave which propagates to layer boundary will disperse in various directions, and we need to analyze considering dispersion of wave. For simplification, we suppose that energy dispersion form at layer boundary and in the same layer, does not change in a horizontal level and therefore, horizontal direction wave number is distributed at the same depth uniformly. As for energy of wave moving to layer boundary, vertical component is the biggest, and the component that incident angle to layer boundary is big, becomes small. We suppose that the energy of incident wave per unit area will disperse with distribution of elliptical shape to represent dispersion of this energy concretely. The energy of incident wave is equal to an area of this ellipse.
We analyze scattering phenomenon by 1 dimensional wave theory.
When we compare simulation result with the amplification function of the record provided by vertical array observation, this scattering model reproduce the peak value well by using the realistic damping value.

KEYWORDS

scattering model; dispersion phenomenon; 1 dimensional analysis; dynamic analysis; multi-reflection; amplification function; energy distribution of elliptical shape; vertical array observation

INTRODUCTION

The multi-reflection method explains the major characteristics such as maximum acceleration distribution and response spectrum or resonance frequency of seismic ground motions well. But, the amplification function by multi-reflection method has a sharp peak in comparison with observation result generally. We need to use more than several times value of damping to be provided from an experiment to reproduce the peak value in the simulation result using this method.

In late years, observations of seismic ground motions are enforced on the many places, and necessity to elucidate the phenomenon that isn't explained by multi-reflection method is pointed out.
As the major cause that the ground vibration is restrained, we can understand as the phenomenon that horizontal direction wave number is coupled by scattering at the layer boundary.

Takenaka (1990) and Fukui *et al.* (1994) do the analysis that consider the layer boundary of wavy pattern. And, Fujitani *et al.* (1994) do the analysis that give a fluctuation of anisotropy to the properties of matter. These analysis are 2 dimensional one either. Many parameters and trial and error are necessary for these numerical calculations, and there are still few numerical results to reproduce a real phenomenon.

We consider that layer boundary isn't smooth like a mirror, but unevenness, and examine the model which can express the amplification characteristic of soft ground basing on the record provided by vertical array observation.

SCATTERING MODEL

When layer boundary is uneven, it is supposed that the wave which propagates to layer boundary will disperse in various directions, and we need to analyze considering dispersion of wave. We pay attention to energy of wave to consider dispersion of wave. For simplification, we suppose that energy dispersion form at layer boundary and in the same layer, does not change in a horizontal level and therefore, horizontal direction wave number is distributed at the same depth uniformly. Even in the case of S wave, P and PV waves exist by scattering and reflecting, but we suppose that these can be ignored. We can reduce a quantity of calculation by these assumption largely. Furthermore, it is possible to estimate dispersion phenomenon without using the information that we can't grasp in detail such as unevenness state of boundary or fluctuation of property of matter.

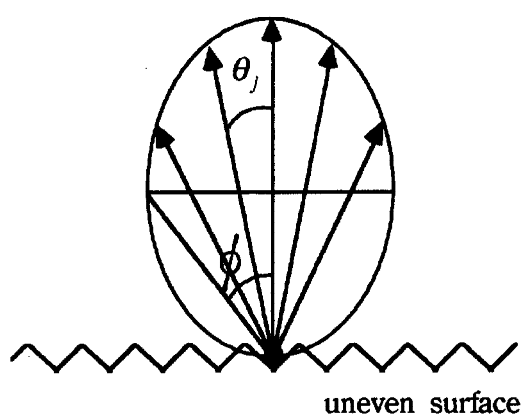

Fig. 1. A supposition of scattering of wave on the uneven surface

As for energy of wave moving to layer boundary, vertical component is the biggest, and the component that incident angle to layer boundary is big, becomes small. We suppose that the energy of incident wave per unit area will disperse with distribution of elliptical shape shown in

Fig. 1 to represent dispersion of this energy concretely.
The energy of wave of angular frequency ω propagating the inside of the elastic body of density ρ, S-wave velocity V_S is

$$K = \pi\rho\omega V_S |E|^2, \tag{1}$$

per a period. Where E is a displacement amplitude.
When sets up as minor axis / major axis ratio with $\tan\phi$ to examine ellipse shape, elliptic area is

$$S = \pi \tan\phi, \tag{2}$$

and when n divides ellipse equally with $\Delta\theta$, the area of a piece which angle θ_j ($\theta_j = j(\Delta\theta)$) inclines from vertical is

$$S_j = 2\left(\frac{\cos\theta_j}{\cos^2\theta_j + \sin^2\theta_j / \tan^2\phi}\right)^2 \Delta\theta. \tag{3}$$

The energy of incident wave is equal to an area of this ellipse.
Because the square of amplitude is in proportion to energy, the amplitude of wave propagating to θ_j direction is

$$E_j = \sqrt{\frac{S_j}{S}}\, E. \tag{4}$$

The wave propagating to the θ_j direction that inclines from vertical passes distance of $1/\cos\theta_j$ times of thickness of layer while losing energy by internal damping, and reaches the next layer. The amplitude when the wave reaches the next layer is

$$E_j' = \sqrt{\frac{S_j}{S}}\, E \exp(ik\frac{H}{\cos\theta_j}). \tag{5}$$

Where H is thickness of layer, and k is a wave number.
When energy of wave which dispersed reaches the next layer, the energy gathers on a top of ellipse adversely in previous case. Accordingly, the displacement amplitude of the wave which reaches the next layer becomes

$$E' = \frac{1}{\sqrt{S}} \sum_{j=1}^{n} \left\{ \sqrt{S_j} \exp(ik\frac{H}{\cos\theta_j}) \right\} E. \tag{6}$$

The wave reaches ground surface while repeating such dispersion and an assembly between layers. A reflection wave repeats a similar process and reaches a base, too. The amplification characteristic is given by all amplitude that let incident wave and a reflection wave repeat.
A simplified scattering model as described above is realistic modeling than the multi-reflection model which considers vertical propagation of shear wave without scattering.

RESULT

A simulation with 2 layers model

We analyze the simple layer model shown in Fig. 2 to examine the effectiveness of this scattering model. We show the result in Fig 3. The amplitude of the amplification function does decrease as lets degree of scattering increase, and that peak position slips off in low frequency side is shown.

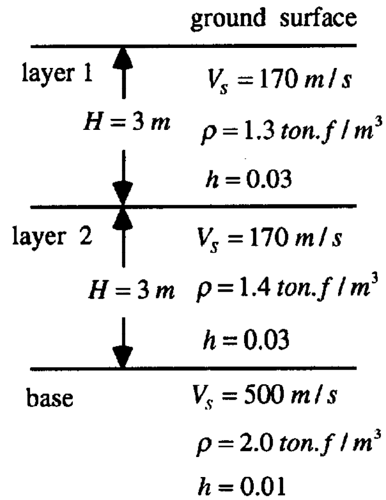

Fig. 2. A simple layer model for numerical computation
H: layer thickness, V_S: shear wave velocity,
ρ : weight density, h : damping ratio.

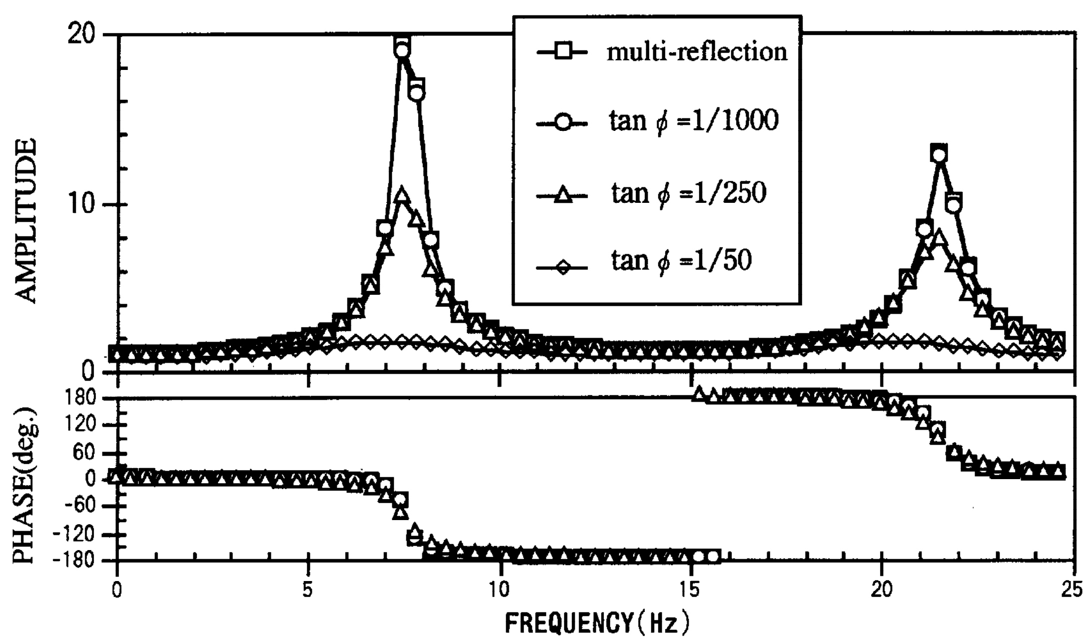

Fig. 3 The amplification function (ground surface / base)

Comparison with observed records

We have observed the ground motion in cooperation with the departments concerned in Narashino campus of Nihon university since 1992 to grasp the characteristic of seismic ground motions. Fig. 4 show the geophysical logging result of the observation point and the positions of seismometers arranged on the ground surface and 4 points in the underground.

We remove preliminary tremor part and the latter half part and took out only principal shock part to simulate horizontal direction behavior, and calculate the amplification function of the observed ground vibration. The amplification function of NS direction is a little different from one of EW direction. On this account, we average the amplification function of NS direction and one of EW direction.

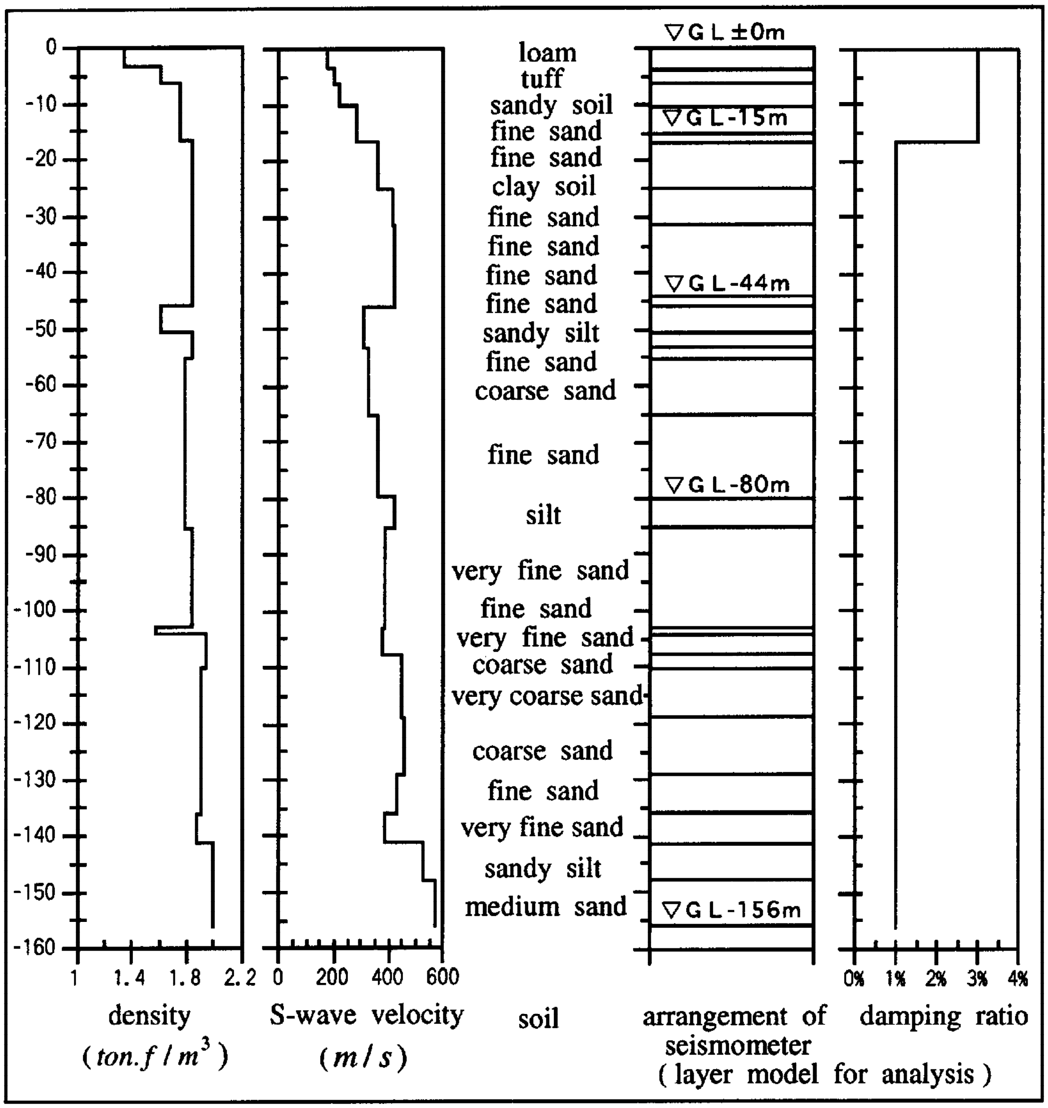

Fig. 4 The geophysical logging result of the observation point and layer model for numerical computation.

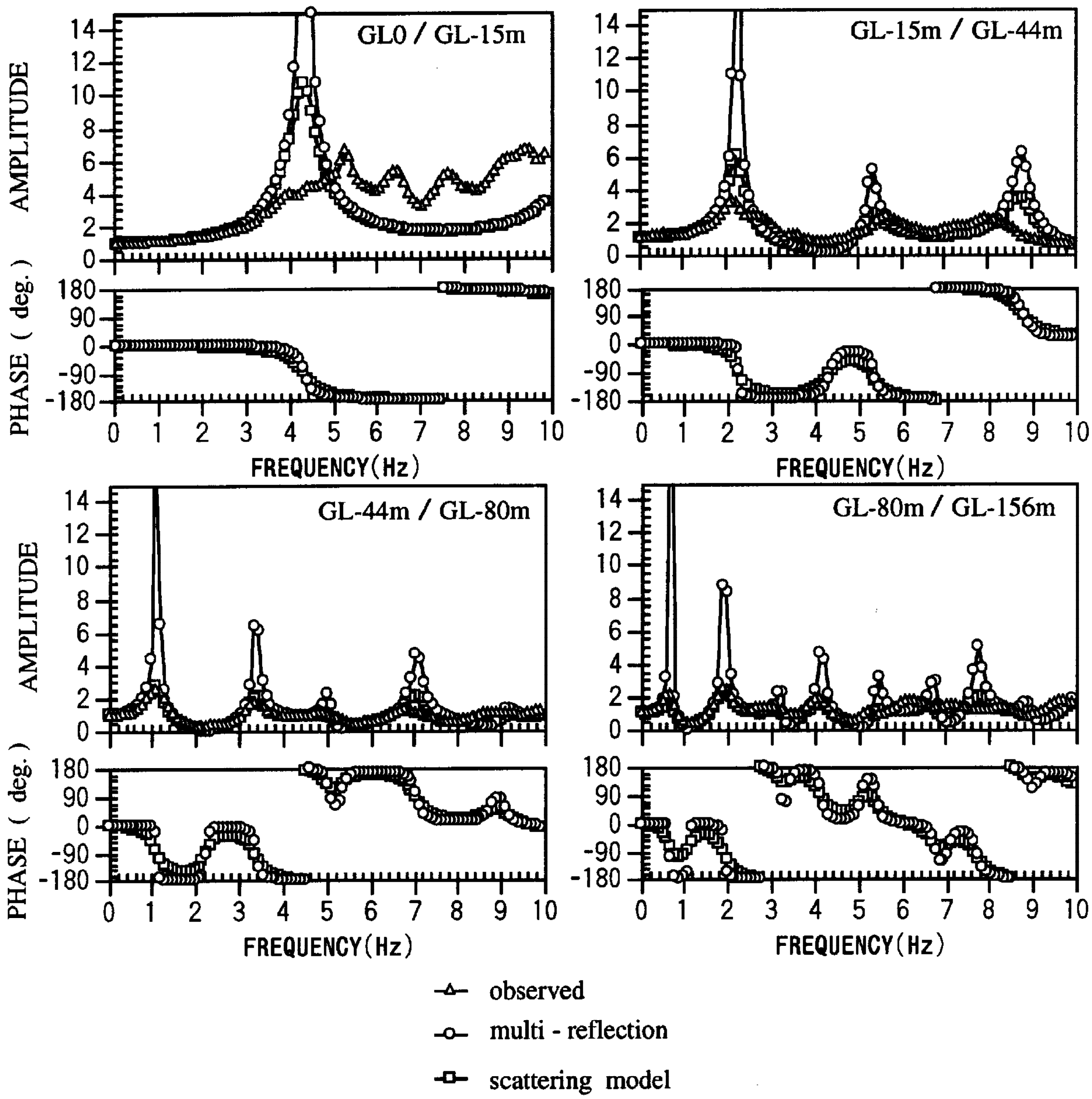

Fig. 5 The amplification function

We calculate each amplification function that suppose energy distribution of elliptical shape ($\tan\phi=1.0\%$) at all layer boundaries of the stratum model shown in Fig. 4. The averaged amplification function (observed value), numerical solution by multi-reflection method and numerical solution by scattering model are shown in Fig. 5. In a place near by resonance point, the amplitude by multi-reflection method is bigger than the observed peak, but, in scattering model, the amplitude does decrease and gets closer to observed value.
And, scattering model can reproduce phase difference of the amplification function same as multi-reflection method well. In this energy distribution of ellipse shape used in numerical analysis, the wave energy more than 80 % is dispersed to the direction that an angle from vertical is smaller than 0.6 deg.

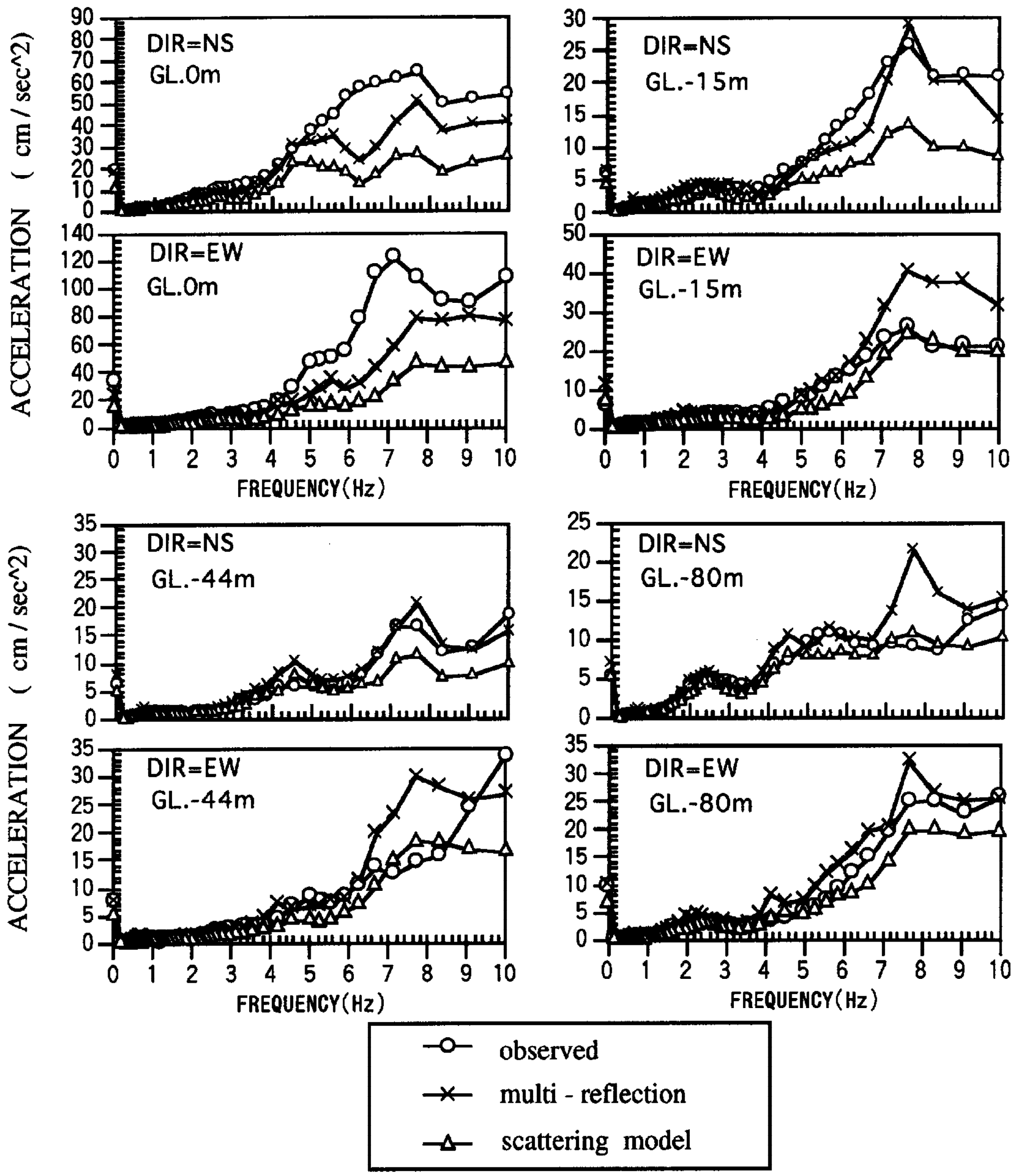

Fig. 6 The acceleration response spectrum

Fig. 6 show the response spectrum calculated for one seismic ground motion. Numerical results don't reproduce the observed records well, because we calculate the response spectrum for specific seismic ground motion using the averaged ground model got an individual earthquake record on an average. But it is shown that scattering phenomenon gives big influence to the simulation of the seismic ground motion.

CONCLUSION

When we compare simulation results with the amplification function of the records provided by vertical array observation, we need to use the big damping value to reproduce the peak value in the simulation results that use multi-reflection model, but it is possible for reproducing the peak value well by using the realistic damping value in the simulation results that use this scattering model.

It is shown that dispersion phenomenon give big influence to simulation of earthquake motion by this. It is thought that we can examine a change of dispersion characteristic of earthquake motion in future by the thing that dispersion energy distribution is optimized, and the good ground model of approximation is got more.

The observed records used in this report have been provided by a process of joint studies with College of Science and Technology, Nihon University and Nishimatsu Construction Co., Ltd. We refer it and thank you for the persons concerned.

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