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COMPARISON OF SPATIAL VARIATION OF SEISMIC MOTION IN THREE DIFFERENT GEOLOGICAL CONDITIONS

M. HORIKE and Y. TAKEUCHI

Architecture Department, Osaka Institute of Technology
Omiya 5-16-1, Asahi-ku, Osaka 535, Japan

ABSTRACT

Spatial variation of seismic motion is examined using seismic motions obtained by small size arrays (a few hundred m in diameter) deployed on three different geological conditions: Paleozoic rock, diluvial, and alluvial formations. Spatial waveform variation of seismic motion of diluvial formation is much greater than those of Paleozoic rock. It is evaluated with the cross-correlation coefficients(CC). The CC of the Paleozoic-rock array data is obviously larger than those of diluivial array data above 3Hz.. This result means that random inhomogeneity of diluvial sediments strongly influences seismic motions above this frequency. The attempt is made to estimate statistical properties of the random inhomogeneity of sediments by a numerical method using this result. It, however, reveals that the standard deviation of the random inhomogeneity is the most effective parameter and without knowing precise value of it the other statistical parameters can not be inferred. Amplitude variation of alluvial array data is much larger than that of diluvial array data. This is supposed to be caused by layered random subsurface structures from geological information and is demonstrated by the numerical simulation.

KEYWORDS

Random inhomogeneity; spatial variation; array seismic motions; cross-correlation; sediments ;simulation

INTRODUCTION

Seismic damage often shows strong spatial variation. In extreme cases the level of seismic damage is quite different even a few tens m apart. This phenomenon is caused not only by the difference in strength of structures but also by the spatial variation of seismic motions in small areas. The spatial variation of seismic motions is confirmed in many small-size array experiments (Abrahamson, 1985, Horike *et al.*,1990, Kataoka *et al.*, 1990, Ishii *et al*, 1990). Therefore, the prediction of it is important for the microzonation. It also influences the vibration of structures during strong seismic motions in such a way that it reduces the translational motion and excites the torsional motion(Somerville *et al.*, 1988). Therefore, it must be taken into account in earthquak-resistence design.

The spatial variation of seismic motions is generated primarily by two factors. The first one is a seismic source. Seismic source is extended so that seismic waves radiated from subareas may reach to different sites at randomly. It results in the spatial variation of seismic motions. The other one is the scattering due to random inhomogeneity along propagation path. In particular, the random inhomogeneity of sediments is a main cause of the spatial variation of seismic motions within small areas. We study the effects of the random inhomogeneity of sediments on the spatial variations of seismic motions in small areas (a few hundred m in diameter).

We first demonstrate from recorded array data that the random inhomogeneity of sediments strongly contribute to the spatial variation of waveform and amplitude. Then, we show preliminary results of numerical simulation. The first one is an attempt to infer parameters of statistical properties of the random inhomogeneity. The second one is the demonstration of the amplitude variation in a layered random subsurface structure.

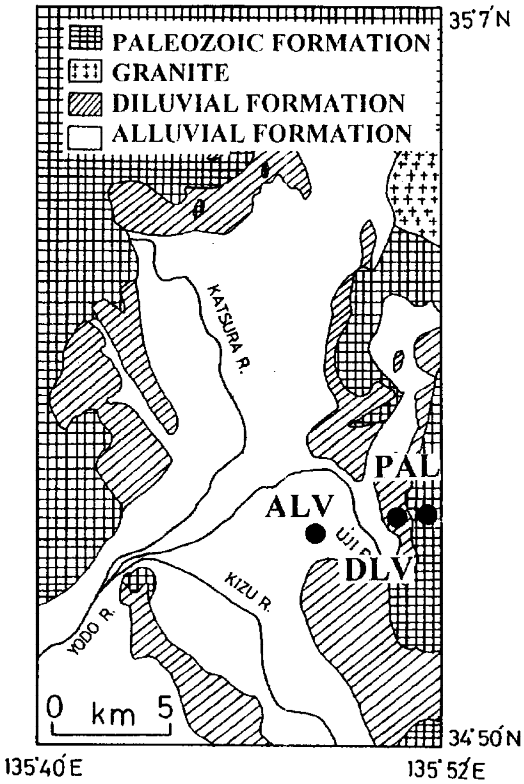

Fig. 1. Surface geological map of the Kyoto basin where three arrays were deployed. The solid circles show the locations of the array experiment.

ARRAY OBSERVATION AND GEOLOGICAL CONDITIONS

Figure 1 shows geological map of the Kyoto basin where three array experiments were conducted. Seismic data were obtained by the arrays deployed in three different geological conditions: Paleozoic rock, diluvial and alluvial formations. We hereafter refer to the three array locations as PAL, DIL, and ALU. The Paleozoic rock is supposed to be the basement rock at DLV and ALV. At DLV the diluvial layer of the thickness of about 500m overlies on the basement rock. At ALV the alluvial layers of the thickness of about 10m overlie the diluvial layer of thickness. A mean S velocity of the diluvial layer increases from 400m/s to 1000m/s with depth.

SPATIAL VARIATION DUE TO RANDOM INHOMOGENEITY OF SEDIMENTS

Waveform Variation

Figure 2 shows an example of seismic traces and the array configuration at DLV. We can see that the waveform are gradually varied from sites to site. This waveform variation is evaluated using the cross-correlation coefficients (abbreviated as CC). At this site the other small array was deployed. The CC is estimated from the data obtained with these two arrays and is shown in Fig. 3. The CC decreases as the frequency and the distance increasing. In particular, seismic motions at sites separate over some distance are almost incoherent above 6 Hz. Specifically, seismic motions at 6 Hz are shaking independently over 100m apart, at 12 Hz over 70 m apart, and 24 Hz over 40m.

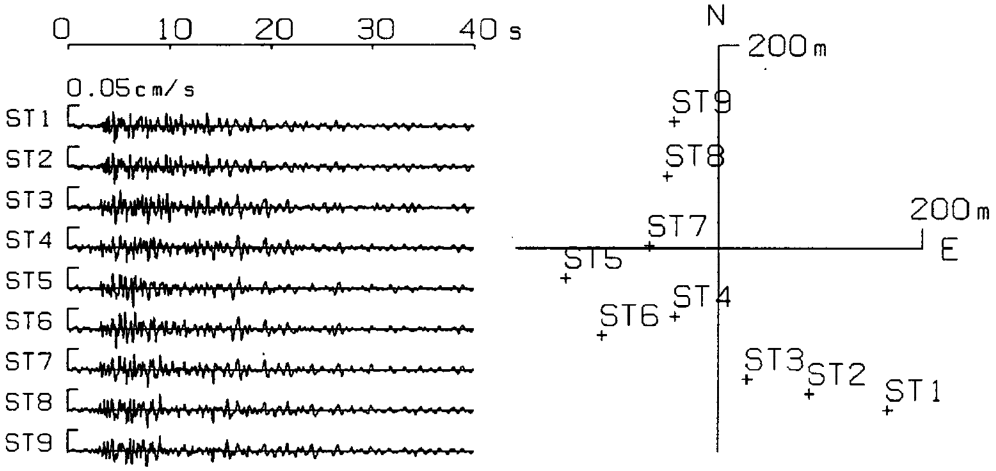

Fig. 2. Example of seismic traces acquired by the array deployed at DIL. The right diagram shows the configuration of the array.

Figure 4 shows the CC at PAL It scatters in a wide range for short distance and at low frequencies. This is supposed to be due to the effect of topography. Because the seismometers were installed on a geometrically complicate rock surface, the difference of incident angle generates the spatial waveform variation more efficiently. The CC at PAL is obviously larger at least above 3Hz than that at DLV whose average is shown in the figure by a solid curve. Taking into account of the effects of the topography and the near-surface inhomogeneity, the CC of seismic motions incident to the sediments are larger and less scattered than the CC at PAL This means that the random fluctuation of P-, S-velocity and density of sediments influences spatial variations of seismic motions above 3 Hz

Amplitude Variation

Figure 5 shows an example of seismic traces at PAL and the array configuration. They are spatially varied not only in waveform but also in amplitude. We next show that this amplitude variation depends on sites rather than seismic events. Figure 6 shows the spectral ratios of four events with reference to ST1. They are similar at every site, being independent on events but are changing from site to site. This fact means that the amplitude spatial variation is caused by near-surface inhomogeneity because the distance between adjacent sites is short about 70m. On the contrary to large amplitude variation at ALV, it is very small at DLV. As described in the section 2, main geological difference between ALV and DLV is the existence of alluvial layer: at ALV the alluvial layer overlies on the diluvial layer, but at DLV it does not. Therefore, we suppose that the existence of alluvial layer is the cause of large spatial amplitude variation.

STATISTICAL PROPERTIES OF RANDOM INHOMOGENEITY OF SEDIMENTS

Statistical properties of random inhomogeneity of sediments must be known to evaluate quantitatively the effects of them to seismic motions. The statistical properties of them is specified for vertical cross-correlation coefficients **C** as

$$\mathbf{C} = \sigma^2 \exp\left(-\left|\mathbf{z}/\mathbf{Z}\right|^{\mathbf{n}}\right) \qquad (1),$$

where σ is standard deviation of the random inhomogeneity for the depth, and **z** and **Z** denote the correlation distance and relative depth, respectively. Horike *et al.* (1993) estimated the parameters in Eq. (1) from well-logging data of S and P velocities. For S velocity, the ranges of the values for the parameters σ,**z**,**n** are respectively between 10% and 20%, between 1m and 3m, and between 0.4 and 1. For the P velocity, the ranges for the parameters **z** and **n** are almost same as those of S velocity, but the range for the parameter σ is about a half of that of S velocity. The correlation between P and S velocities is high. Equation (1) shows the correlation coefficients for depth direction, but for the evaluation of random media to seismic motions we furthermore know those for horizontal direction. However, we have no information about them. We next attempt to infer the parameter of random media for horizontal direction.

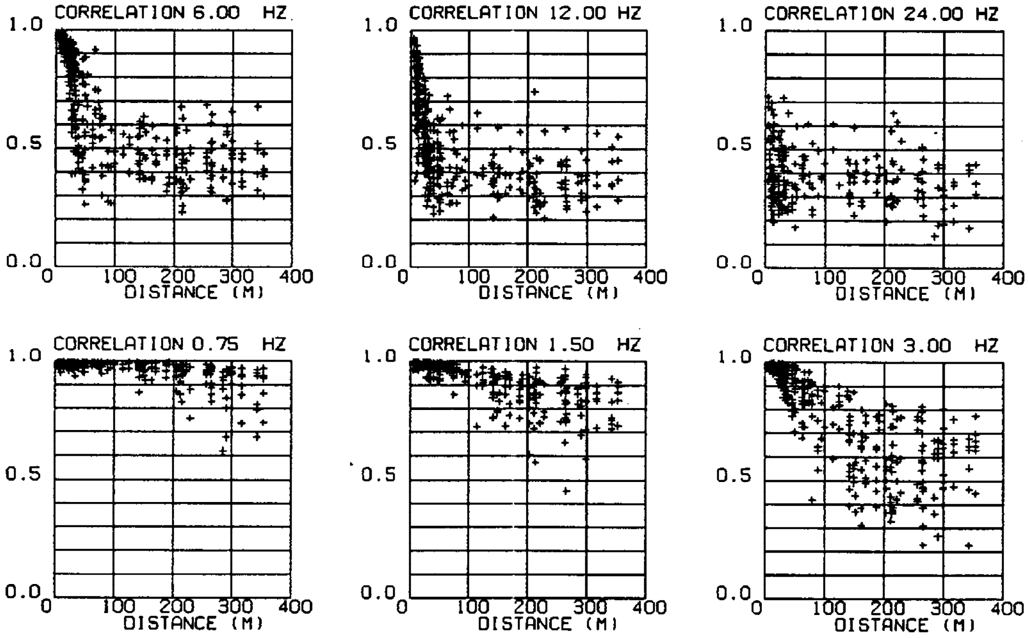

Fig. 3. Cross-correlation coefficients estimated from array seismic data of PAL at frequencies 0.75, 1.5, 3.0, 6.0, 12.0 24.0 Hz.

SIMULATION

Simulation Method and Subsurface Model

Numerical simulation is performed by the 4-th order finite-difference method (Frankel, 1989). Boundary conditions are as follows: the periodic boundary condition is employed for the right and left boundaries, the free surface condition for the top boundary, and the absorbing boundary condition for the bottom boundary. The grid size is 1 m for the horizontal and depth directions. A two-dimensional SH problem is treated. Only the S velocity is fluctuated and the density is fixed. The randomly inhomogeneious S subsurface structure is created as follows. The fluctuation of the S velocity is generated by a computer for given parameter of the statistical properties. They are added to the mean subsurface structures of DIL and ALV which are described in section 2.

Inference of the Horizontal Correlation Distance at DIL

As described previously, the horizontal parameters of random inhomogeneity of sediments are not known even now. Therefore, in this section we estimate them. We infer the horizontal correlation distance by fitting the CC shown in Fig. 3 with that estimated from simulated motions. Figure 7 shows the CC at frequencies 1.5 Hz, 3 Hz, and 6 Hz inferred from seismic motions simulated for three random subsurface structure models of DIL. The horizontal correlation distances of these models are 5m, 10m, and 20m. The other parameters are as follows: $\sigma=20\%$, Z=2m, n=1. The CC of simulated motion decreases as the horizontal correlation distance increases. It means the horizontal correlation distance is an effective parameter for the spatial variation of seismic motions. However, it should be noted that the CC from simulated motions is lower than that from recorded motions for the range of short relative distance. This means that assumed parameters are not appropriate, because the CC of real array data contains the effects of spatial waveform variation of incident waves and the three dimensional random structures of sediments. Figure 8 shows the CC for another random model. The difference from the previous model is the value of the standard deviation, and for this model it is 10%. The CC in this case is much smaller than that from recorded seismic motions. The large increase of the CC due to the decrease of the standard deviation means that the horizontal correlation distance cannot be inferred without knowing a precise value of it.

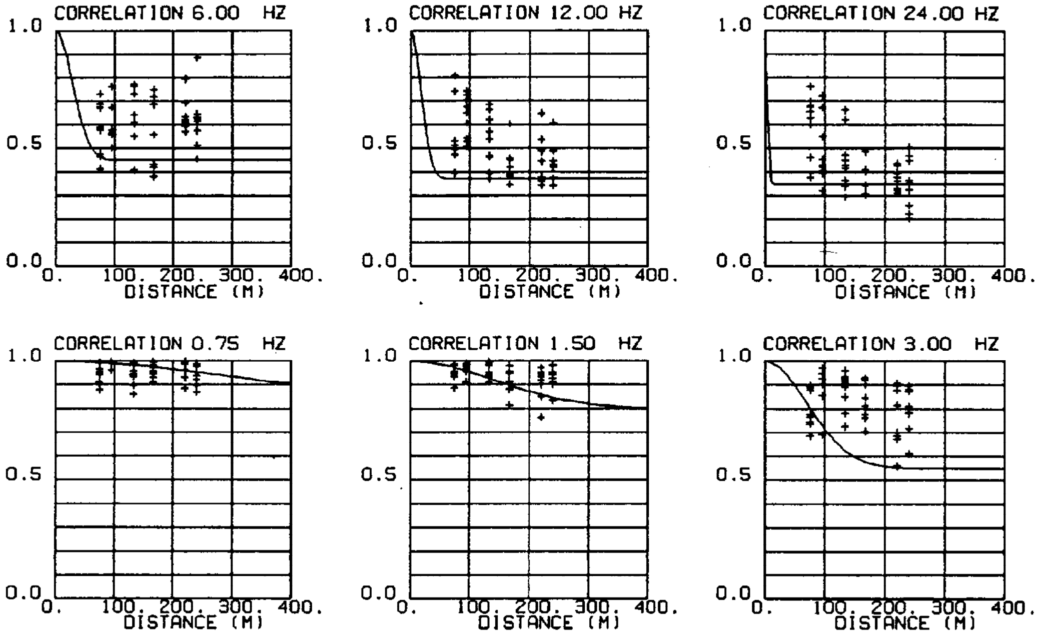

Fig. 4. Comparison of the correlation coefficients at PAL and at DIL. The curved line denotes the average of the correlation coefficients at DIL, and the cross symbols denote estimated cross correlation at PAL.

Amplitude Variation in Layered Random Sediments

At ALV, amplitude is spatially varied more largely than at DLV. It is supposed to be caused by a layered random subsurface structure. Therefore we demonstrate it numerically. Comparison of amplitude variation is made for three models: the S velocity in lower and upper layers is fluctuated (model 1), the S velocity only in the upper layer is fluctuated (model 2), and that only in the lower layer is fluctuated (model 3). Simulated seismic motions are shown in Fig. 9. Amplitude variation for the model 2 is much larger than that for the model 3 and is similar to that for the model 1. This result means that layered random media increase the spatial amplitude variation.

CONCLUSION

We obtain the following three conclusions.

(1) Seismic motions above 3 Hz is strongly influenced by the random inhomogeneity of sediments.
(2) Spatial amplitude variation become large in layered random sediments.
(3) Precise value of standard deviation is necessary to determine the horizontal correlation distance from recorded seismic motions.

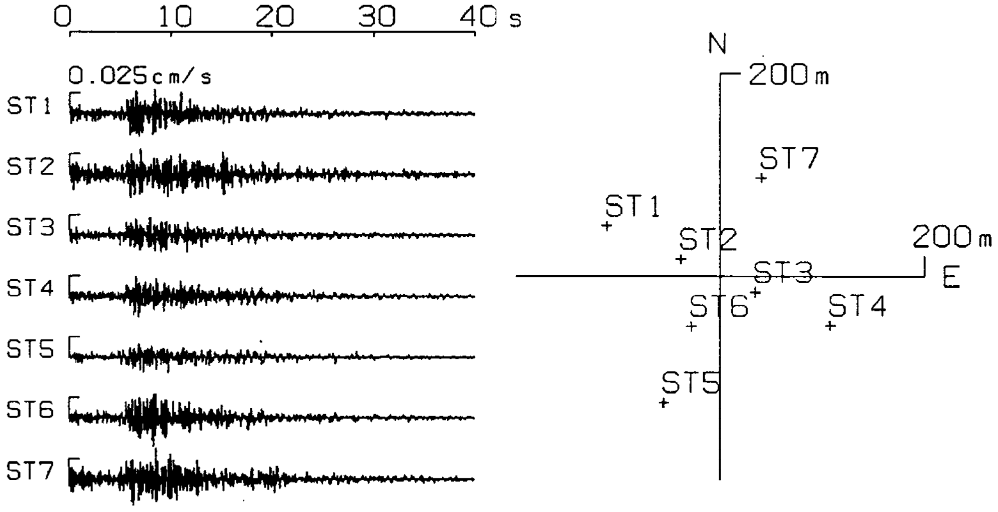

Fig. 5. Example of array seismic traces and the array configuration at ALV.

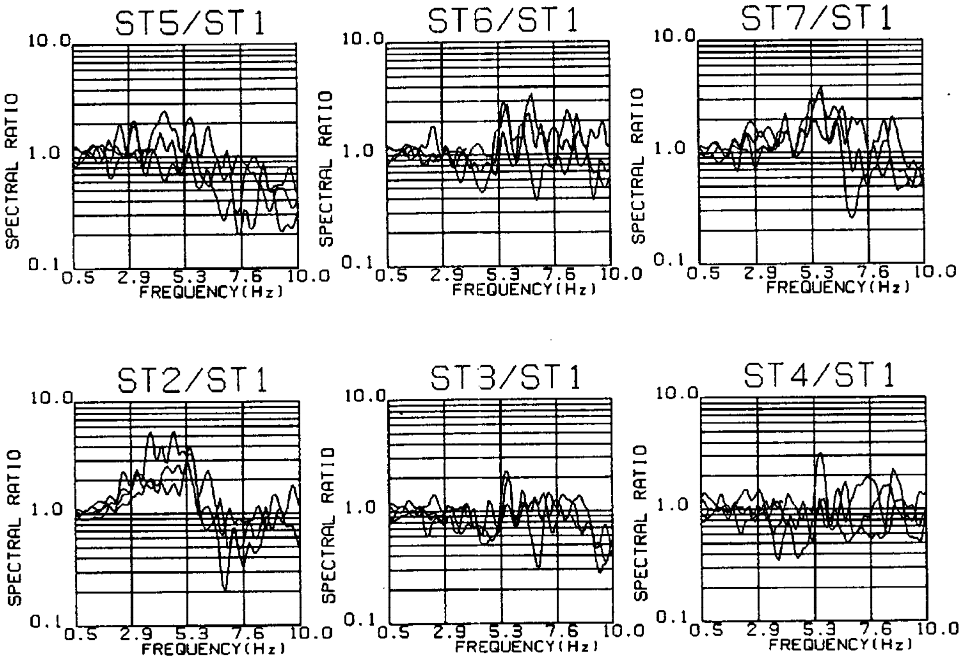

Fig. 6. Spectral Ratios with reference to ST1 shown in Fig. 5 for 4 events.

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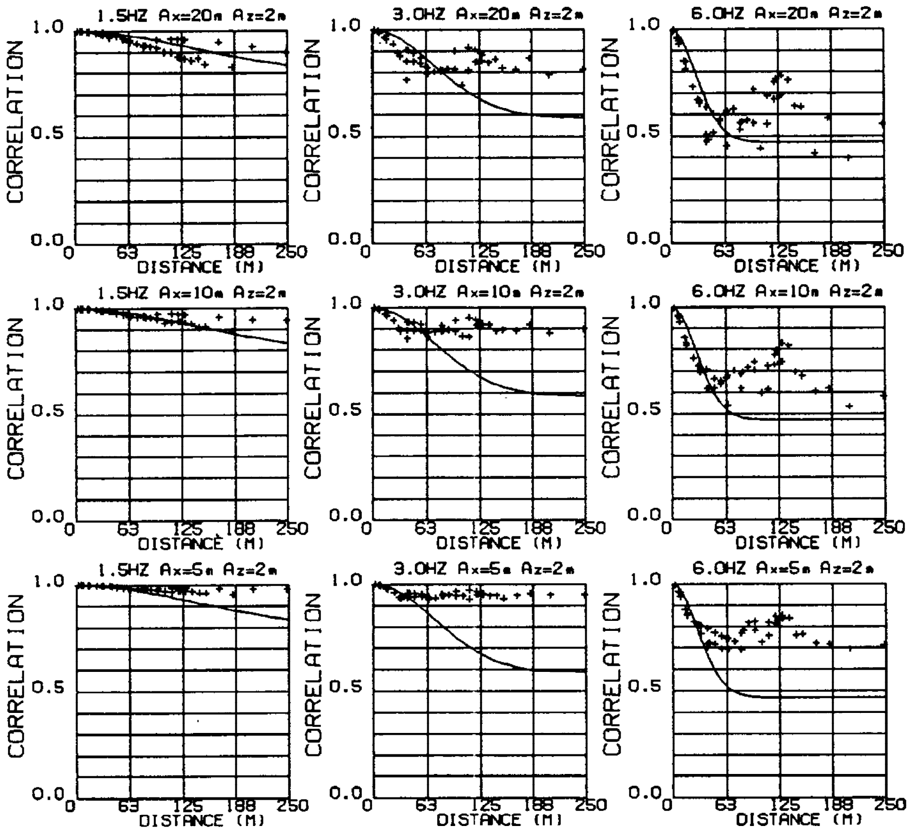

Fig. 7. Comparison of the cross-correlation between three horizontal correlation distances 5m, 10m, and 20m.

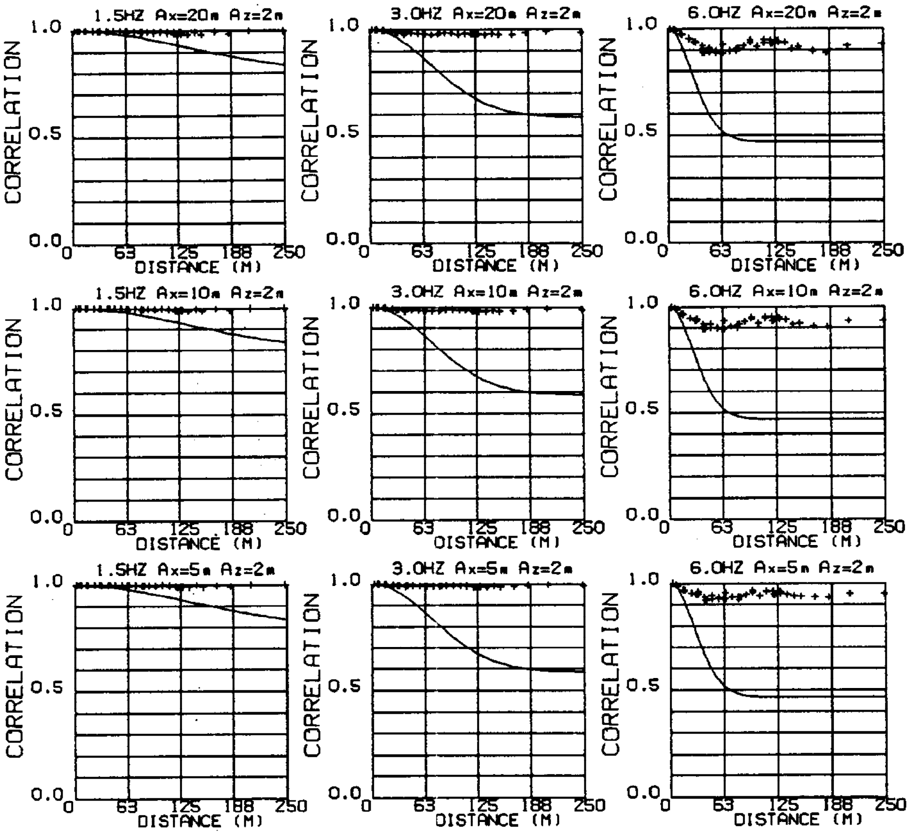

Fig. 8. Same as Fig. 7 except that the standard deviation is different and decreases to be 10%.

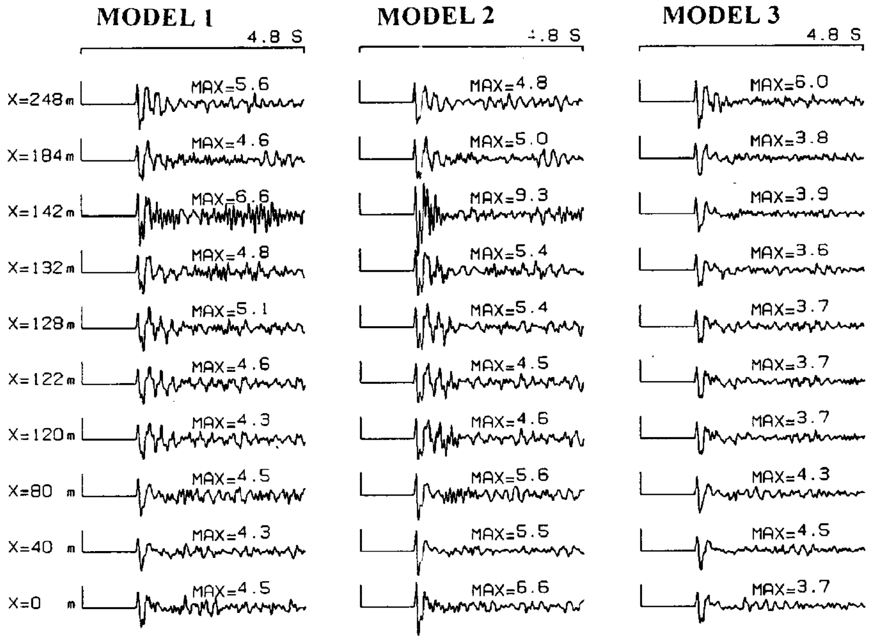

Fig. 9 Comparison of seismic response for three two-layered random subsurface structures.