(70) Spatial Coherence of Ground Motion from Dense Array Records

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INTRODUCTION

Spatial coherency (or incoherency) of ground motion is important in the earthquake response analysis for mult-supported, buried and large-scale structures. However, the characteristics of the spatial coherency, especially that in short separation distance, are not fully investigated primarily because of the lack of the data. The loss of the coherency is generally considered to be caused by the extended seismic source, complicated propagation path from source to site and local heterogeneity. On the other hand, ground motion is three-dimensional vibration in space and nonstationary in time. Thus it is necessary to examine the characteristics of the spatial coherency for the different components and the wave types. The direction dependency of the spatial coherency in short separation distance is also examined in detail.

DATA AND METHOD

The records from Chiba array[1] and Fukushima array are used. The layout of the Chiba array is shown in Fig.1, from which it is convenient to examine the coherence in the separation distance from several ten to several hundred meters. Suppose the ground motions at stations i and j are $x_i(t)$ and $x_j(t)$, respectively, the coherence function $Coh_{ij}(f)$ is defined by Eq. (1), where $S_{ij}(f)$ is the cross spectral density function and $S_{ii}(f)$ and $S_{jj}(f)$ are the power spectral density functions. In order to grasp the tendency of the coherence quantitatively, the coherence $Coh_{ij}(f)$ is fitted by a simple function $\gamma_{ij}(f)$ defined by Eq. (2), in which α is a parameter determined by the least square method. The coherence can be well represented by the fitted curve in most cases. Then the fitted curve $\gamma_{ij}(f)$ is used hereafter instead of the original coherence $Coh_{ij}(f)$.

$$Coh_{ij}(f)=\frac{|S_{ij}(f)|}{\sqrt{S_{ii}(f)}\sqrt{S_{jj}(f)}} \quad \cdots\cdots\cdots (1) \qquad \gamma_{ij}(f)=\frac{1}{1+\alpha \cdot f^2} \quad \cdots\cdots\cdots (2)$$

COHERENCE OF THE DIFFERENT COMPONENTS AND WAVE TYPES

Ground motions are expressed here by the radial, transverse and vertical components, which are generally in accordance with the three principal axes[2], and separated by the P, S and coda phases. The Chiba array records from the 1987 Chibaken-Toho-Oki earthquake ($M=6.7$,

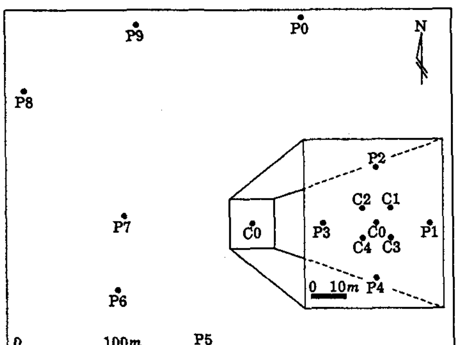

Fig. 1 Layout of the seismometers in Chiba array

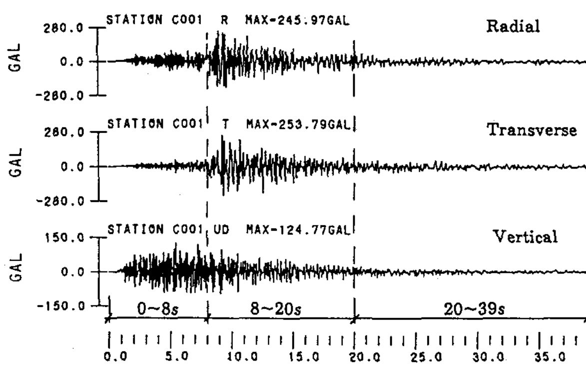

Fig. 2 Wave of the Chibaken-Toho-Oki earthquake

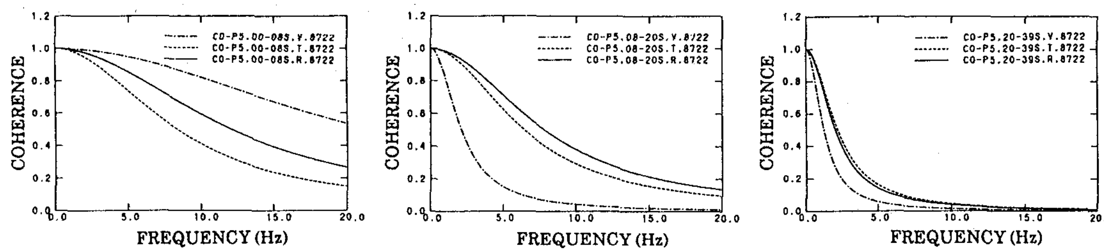

Fig. 3 Comparison of the coherence for radial, transverse and vertical components

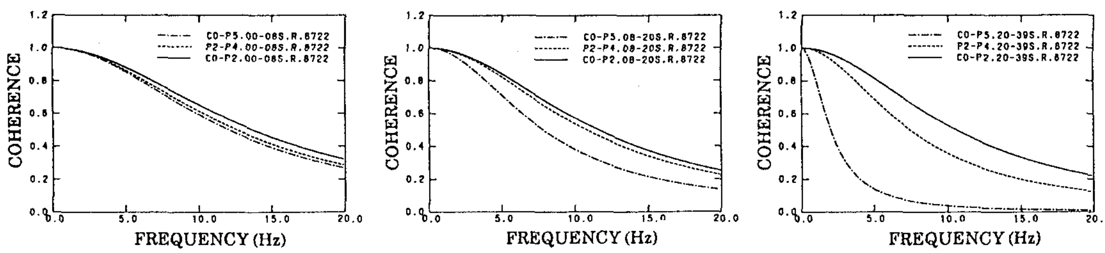

Fig. 4 Decrease of the coherence with separation distance

$\Delta = 45km$) are employed for the purpose of the examination on the coherence of the different components and wave phases. The time histories of the three components are given in Fig. 2, in which the time windows roughly corresponding to the P (0-8s), S (8-20s) and coda (20-39s) phases are indicated. There are 9 combinations from the three components and the three wave phases. The fitted curves of the coherence between C0 and P5 (124*m* separation) are shown in Fig. 3 for the 9 combinations. It is clear that the coherence of the three components are substantially different in the P and S phases and relatively close to each other in the coda phase. The coherence of the vertical component is higher than that of the horizontal components in the P phase, but lower in the other cases. Of the three wave phases, the P wave shows the highest and the coda shows the lowest coherence. The P phase consists mainly of the directly arrived P wave, while in the S phase besides the directly arrived S wave, the scattered P waves are also involved. In addition, the wave length of the P wave is longer than that of the S wave for the same frequency, which abates the wave passage effect. This may explain the difference of the coherence of the different wave phases.

The most important characteristics of the coherence are the decrease of the coherence with the frequency and separation distance. Figure 4 compares the coherence of the radial component of 15, 30 and 124*m* separation distances for the three wave phases. From this figure it is obvious that the loss of the coherence with the separation distance has different gradient for the P, S and coda phases. The loss of the coherence in the P phase is less than that in the S phase. The coherence of the coda phase attenuates the most rapidly.

DIRECTION DEPENDENCY OF THE COHERENCE

It is considered that the coherence in the direction orthogonal to the epicentral direction is higher than that in the epicentral direction with the same separation distance because of the wave passage effect[3][4] (time delay). The direction dependency of the coherence in short separation distance is examined here. On the other hand, it is also necessary to examine the coherence for the body wave and surface wave separately because the propagation paths of them are different. The Fukushima and Chiba arrays are used for this purpose.

Body Wave

Results from the Fukushima Array Records The arrangement of the Fukushima array and the epicenter of the 1989 Ibaragiken-Oki earthquake ($M=5.6$, $\Delta=80km$) are shown in Fig. 5. The fitted curves of the coherence from the Ibaragiken-Oki earthquake records between NV1 and NV3, NV3 and NV5 and NV5 and NV1 are shown in Fig. 6. In this case, the effects of the source, propagation path, site condition and separation distance can be regarded as the same. Therefore the difference between these three curves is considered mainly due to the difference of the direction of the coherence with respect to the epicentral direction. It is noticed that while the coherence of radial component between NV3 and NV5 is the lowest, that of the transverse component is the highest of the three curves. In Fig. 6 the relation of the coherence with d_L, the projected distance of the separation distance in the epicentral direction, is also shown. It is observed that the direction dependency of the radial and transverse components indicates a contrary tendency, i.e., the coherence decreases as the d_L decreases for the radial component, but decreases with the increase of the d_L for the transverse component.

Results from the Chiba Array Records The records of the 1989 Ibaragiken-Nanseibu earthquake ($M=5.6$, $\Delta=48km$) are used to examine the direction dependency of the coherence at the Chiba array site. The epicenter of this event is in the azimuth of N22°W. The fitted curves of the coherence between P1 and P3, P2 and P4 (both 30m separation), P3 and P5 (119m) and P3 and P6 (129m) are compared in Fig. 7. Although there exists little difference between the curves of the coherence for P1-P3 and P2-P4, those of P3-P5 and P3-P6 are slightly different. The coherence of the radial component for P2-P4 and P3-P5, which are noted as parallel in Fig. 7, is found slightly higher than that for P1-P3 and P3-P6 which are noted as normal. The coherence of the transverse component shows an opposite trend. This is in agreement with the results obtained from the Fukushima array records.

Surface Wave

The coherence of the surface wave is investigated using the records of the Chiba array from the 1984 Naganoken-Seibu earthquake ($M=6.8$, $\Delta=232km$, Epicenter=N84°W). The time histories of this event are shown in Fig. 8. The time history from 130 to 230s which is considered being the Love wave is used. The dominant frequency of this time segment is about 0.2Hz and little power exists for the frequency higher than 1 Hz. The fitted curves of the

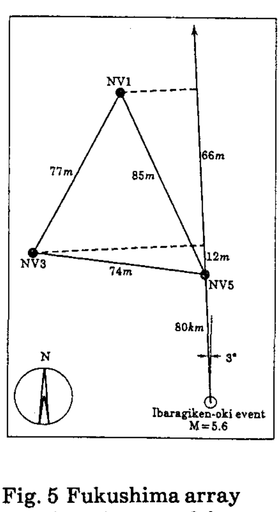

Fig. 5 Fukushima array and the epicenter of the Ibaragiken-Oki earthquake

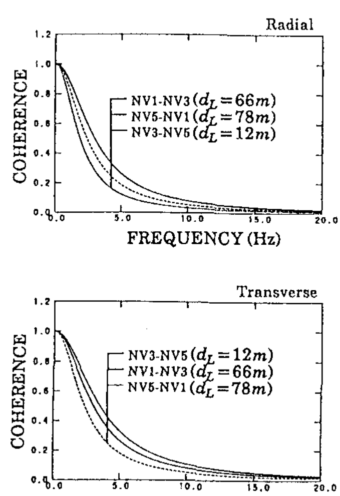

Fig. 6 Coherence from the Fukushima array records

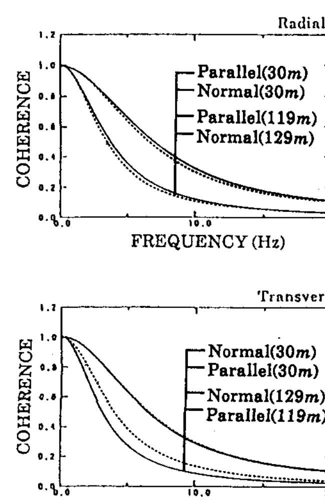

Fig. 7 Coherence from the Chiba array records

coherence of P1-P3, P2-P4, C0-P5 and C0-P6 are shown in Fig. 9. It is found that the coherence at the frequency less than 1 Hz is very close to the unity and that at the frequency higher than 1Hz is almost zero for both radial and transverse components. This is different from that of the body wave whose coherence decreases gradually with the frequency. Although there exists no considerable difference for the coherence parallel and orthogonal to the the epicentral direction, the coherence parallel to the epicentral direction is found slightly higher than that orthogonal to the epicenter direction for both the radial and transverse components, which also differs from that of the body wave.

CONCLUSIONS

The characteristics of the spatial coherence of the radial, transverse and vertical components are investigated for the P, S and coda phases. The coherence of vertical component is higher than that of the horizontal component in the P phase but lower in the other two phases. Of the three wave phases, the P wave has the highest and the coda has the lowest coherence. The direction dependency of the coherence is observed for both the body wave and surface wave, though it is in less extent comparing with the frequency- and separation distance-dependency. For the body wave, the radial component shows higher coherence in the direction parallel to the epicentral direction, but the transverse component shows higher coherence in the direction orthogonal to the epicentral direction. In the case of the surface wave, both the radial and transverse components have higher coherence in the direction parallel to the epicentral direction.

ACKNOWLEDGEMENT: The Chiba array data are made available by the Institute of Industrial Science, University of Tokyo, which is deeply appreciated.

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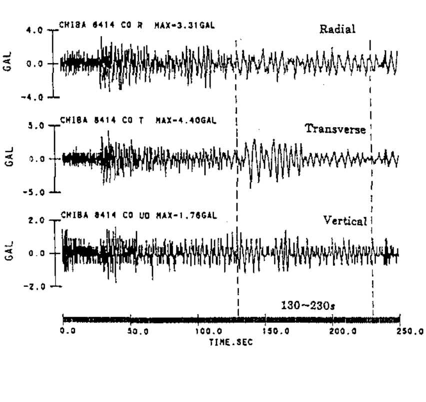

Fig. 8 Wave of the Naganoken-Seibu earthquake

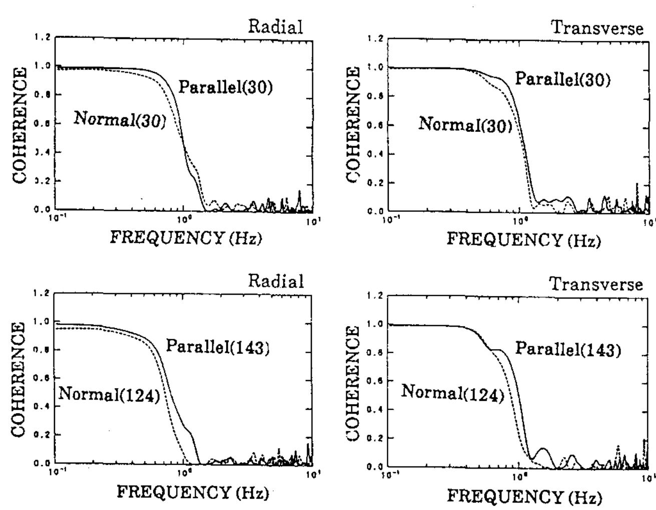

Fig. 9 Coherence from the Naganoken-Seibu earthquake records