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INFLUENCE OF SPATIAL VARIATION OF EARTHQUAKE GROUND MOTION ON RESPONSE OF SECONDARY SYSTEMS

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ABSTRACT

This paper studies the coherence property of the ground motions on the basis of the data of the Kinokawa array where the ground is hard rock, and investigates on the response behavior of secondary systems with high frequency. From the data analysis, it is found that the coherence property tends to diminish with higher frequency of wave components as well as with longer separation distance between two different locations. Comparing the property with those on relative soft ground like SMART-1 array, the coherence is reduced in a high frequency range even on the hard rock ground. Moreover, after modeling the coherence property at hard rock site, it is found through several response analyses that secondary systems with high frequency are affected by the spatial variation of the ground motions. This may lead to more rational seismic design practice for equipmental components of nuclear power plant systems.

KEYWORDS

Spatial variation; nuclear power plant; secondary systems; dense array; hard rock; coherence analysis

INTRODUCTION

In a current seismic design practice of nuclear power plant facilities, earthquake ground motions are assumed to come upward uniformly without spatial variation in a horizontal plane. Earthquake ground motion, however, reveals spatial variability due to inhomogeneity of ground and to presence of various types of waves induced. This has been observed from dense array of earthquake motions such as SMART-1 array . Nevertheless, few observation has been made on hard rock site where nuclear power plants are often built in Japan. Firstly, this paper studies the coherence property of the ground motions on the basis of the data of the Kinokawa array where the ground is hard rock. The coherence analysis is done for the horizontal and vertical components to know the property of the spatial variation on hard rock. Secondly, this paper investigates on the response behavior of secondary systems with high frequency.

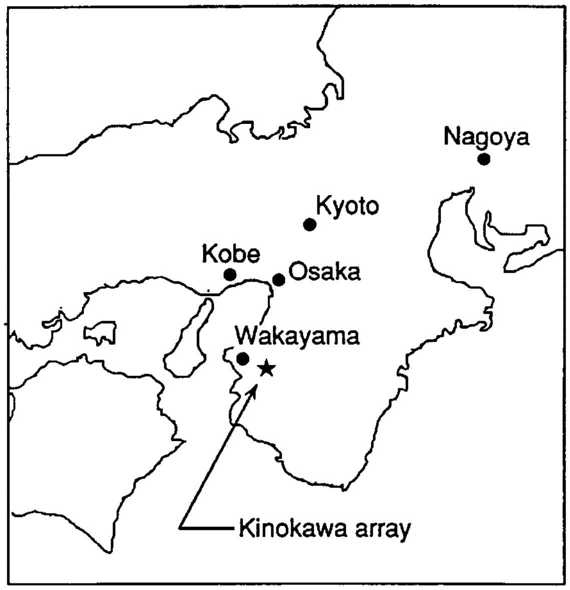


Fig. 1. Location of the Kinokawa array

KINOKAWA ARRAY

The Kinokawa array, which the Kansai Electric Power Company owns in the neighborhood of Wakayama city as seen in Fig. 1, is a horizontal surface array located on the hard rock ground. The configuration of the free-field surface array is shown in Fig. 2. The earthquake observations have been done with accelerometers of 17 components. At the points A, B, C, and E set are triaxial (NS, EW, UD) accelerometers, and at the point D set is a biaxial (NS, UD) accelerometer. The point E is located on a concrete foundation of the electric power substation facilities. All accelerometers are servo types. The triaxial speedometer is also located on the point A(AV). The soil conditions at the point F is presented in Fig. 3 and the shear wave velocity here is about 1050m/sec on the surface.

EARTHQUAKE DATA

From May 1981 to March 1993, 141 earthquakes were recorded at the Kinokawa array. 17 events out of them are selected for this study with their peak acceleration and duration in mind. These earthquakes range in magnitude from 2.5 to 5.6 and in their epicentral distances from 6km to 15km. Horizontal peak accelerations, in average, are from 20.1 to 165.0 Gal and vertical peak accelerations from 7.7 to 68.0 Gal.

DATA ANALYSIS

The coherence analysis has been performed using the horizontal components to capture the property of the spatial variation of the earthquake ground motions on hard rock. An additional analysis has been done using vertical components. The coherence between the ground motions $X_1(t)$ and $X_2(t)$ at a certain frequency ω, $\mathrm{Coh}_{X_1X_2}(\omega)$, is defined as follows:

$$\mathrm{Coh}_{X1X2}{}^2(\omega) = \frac{|S_{X1X2}(\omega)|^2}{S_{X1X1}(\omega)\cdot S_{X2X2}(\omega)}, \tag{1}$$

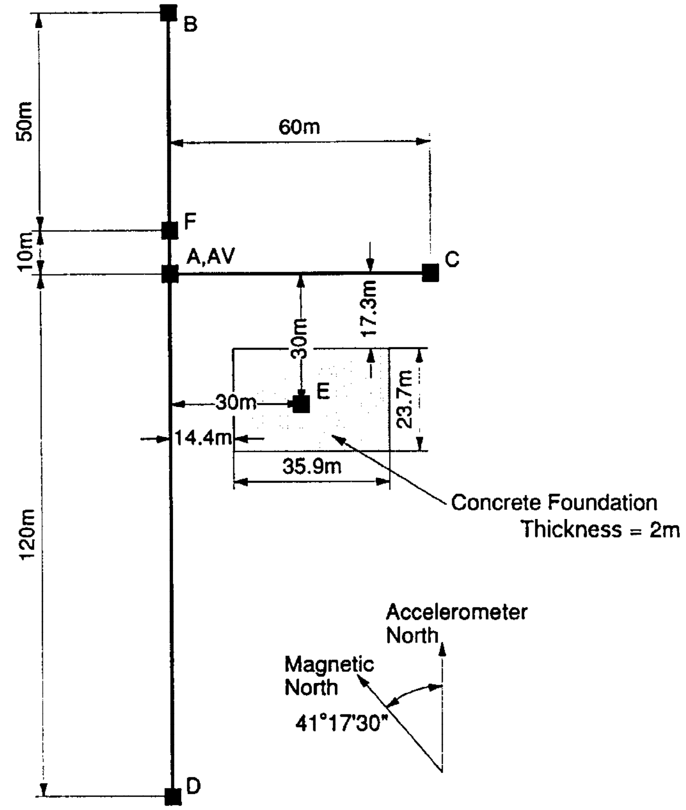


Fig. 2. The Kinokawa array configuration

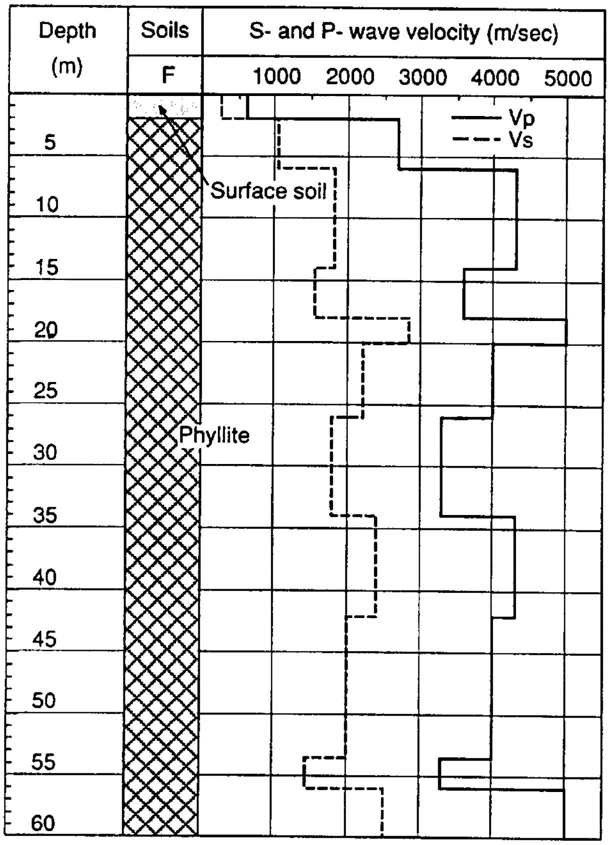
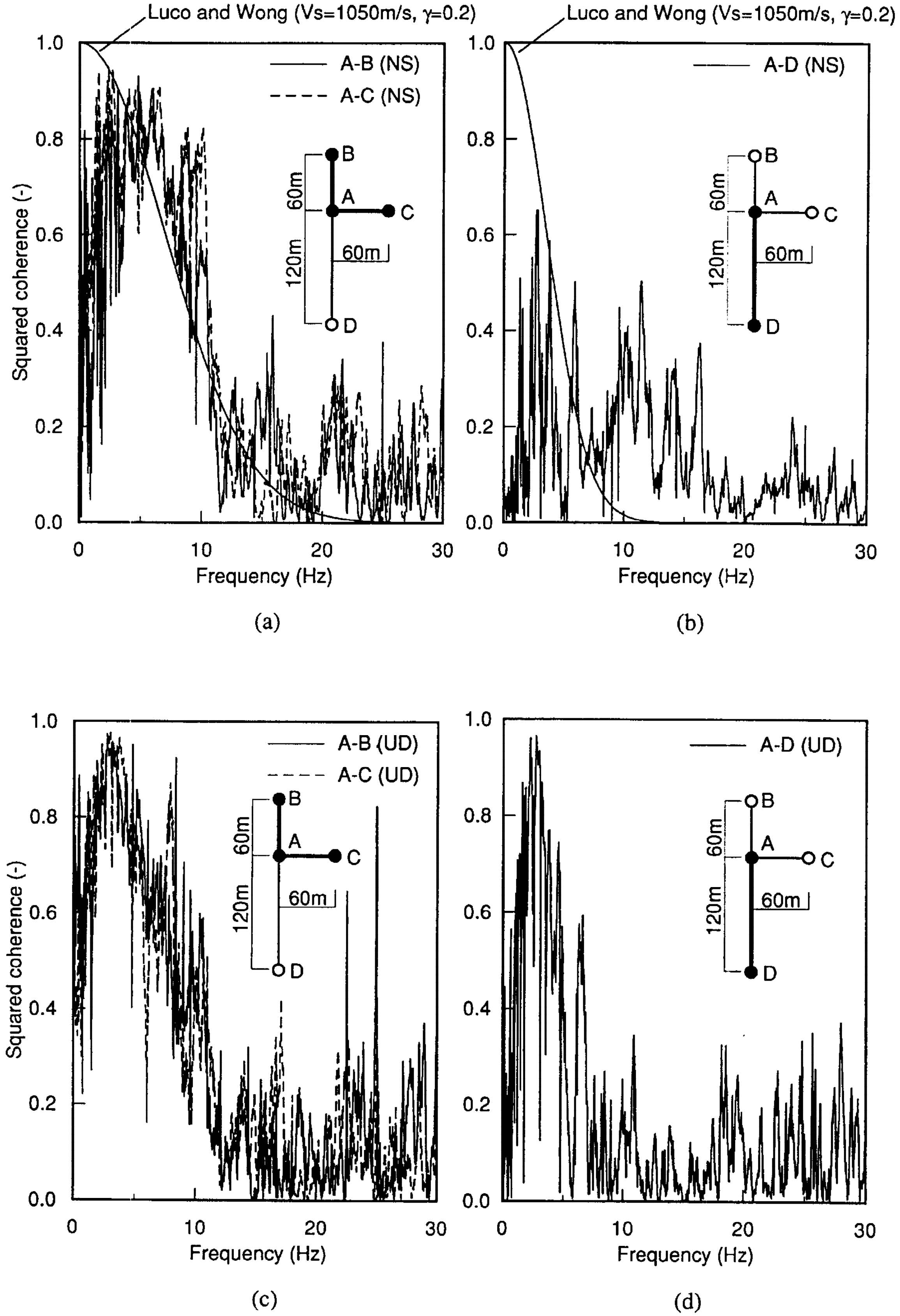


Fig. 3. Soil profile and S- and P- wave velocities



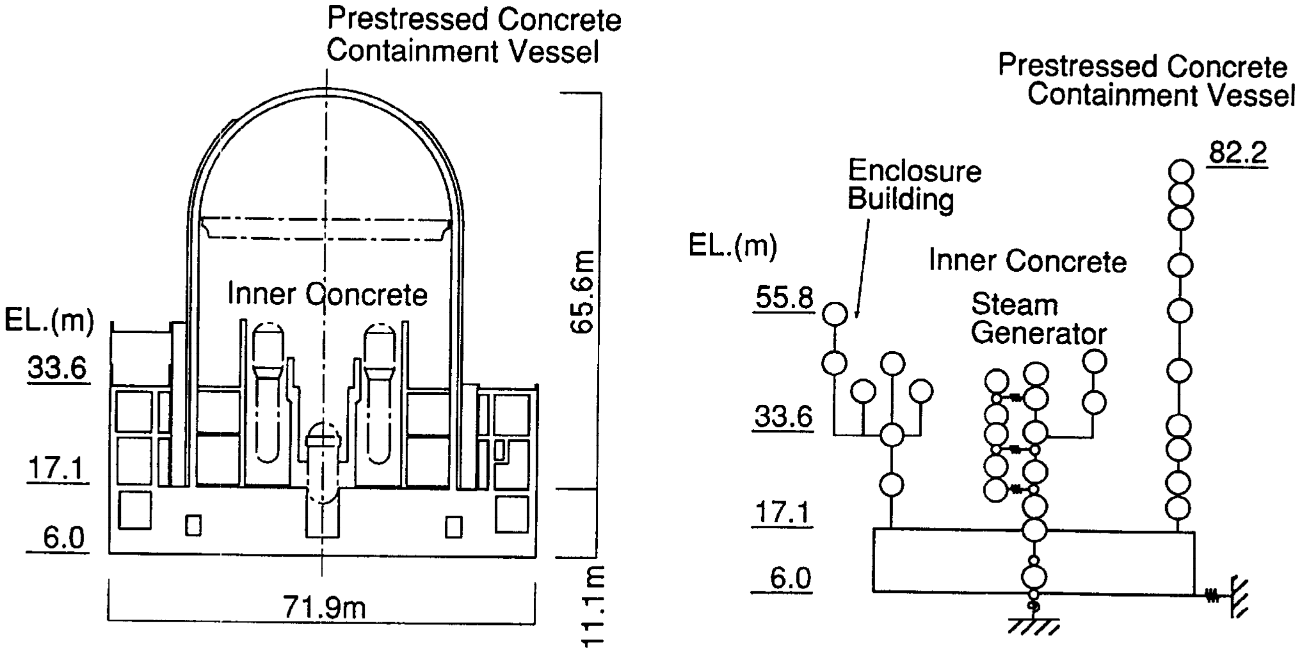
(a)

(b)

(c)

(d)

Fig. 4. Coherence as a function of frequency



(a) Reactor building (b) Lumped mass system

Fig. 5. Analytical model

where $S_{X_1X_1}(\omega)$ and $S_{X_2X_2}(\omega)$ are respectively the ensemble average of the power-spectrum of the two motions, $S_{X_1X_2}(\omega)$ is the ensemble average of the cross-spectrum. The results of the coherence analysis are shown in Fig. 4. These results obviously show that the coherence between different ground motions decays quickly as the frequency becomes higher, and that shorter separation distance yields higher correlation. Although the same tendency can be observed both in horizontal and vertical motions, careful examination reveals more coherent waves propagate in a vertical direction. These results clearly indicate that there exists the effect of the spatial variation of ground motions even on the hard rock, similarly to the soft ground like SMART-1 array site.

Several mathematical models representing spatial variation of horizontal components (Harichandran and Vanmarcke, 1984, 1986; Loh, 1985) have been suggested, which are so-called coherence function. In this study, the single-parameter, second-order function recommended by Luco and Wong (1986) is used:

$$\mathrm{Coh}(r,\omega) = \exp\left[-\left(\frac{\gamma\omega r}{V_S}\right)^2\right], \tag{2}$$

where γ is a dimensionless parameter, V_S a shear wave velocity, and r a separation distance. Under the Kinokawa array site conditions, that is, the shear wave velocity is 1050m/sec on the surface, the dimensionless parameter γ is estimated 0.2 from the data.

RESPONSE OF STRUCTURE

Since the spatial variation of ground motions have much influence in the high frequency range, equipmental components located with a building, whose predominant frequencies are in the high frequency range, are expected to be affected. Therefore, this subsection describes the response analysis to be performed in order to examine the effect of spatiality varying motions on secondary systems in a typical PWR building in Japan, as shown in Fig. 5 (a). The building structure is idealized as a lumped mass multistick system as illustrated in Fig. 5 (b). It is expected here that the response of the secondary systems can be reduced due primarily to the existence of a large rigid mat foundation against the ground motion since the mat foundation serves as a high cut filter to the ground motions (Yamahara, 1970). In the response analysis, the input excitation to the analytical system is the filtered motion so that point excitations are integrated over the foundation under the condition of rigid foundation. This treatment is done by using the following equation:

$$|H(\omega)|^2 = \frac{4}{(LD)^2}\int_0^L \int_0^D (L - r_1)(D - r_2)\mathrm{Coh}\left(\sqrt{r_1{}^2 + r_2{}^2}, \omega\right)\cos\left(\frac{\omega r_1}{c}\right)\cos\left(\frac{\omega r_2}{c}\right)dr_1\, dr_2\ , \tag{3}$$

where the mat foundation is rectangular shape (L×D), c is an apparent wave velocity (Harichandran, 1987). Assuming infinite apparent wave velocity (waves propagate vertically), the redaction ratio spectra, the ratio of the floor response spectra (1% damping ratio) with consideration of the spatial variation of the ground motion to those without considerations, are shown in Fig. 6. As expected, the reduction is more significant in the shorted period range. This is attributable to the large size of the mat foundation. It can also be observed that the reduction ratio is smaller in higher floor levels in the building.

CONCLUSION

This paper models the coherence property of the ground motions on the Kinokawa array where the ground is hard rock, and investigates on the response behavior of secondary systems with high frequency. The results presented in this paper is as follows:

1. The coherence model is identified for the hard rock site, for which no previous work has been done so far. Comparing the property with those on relatively soft ground like a SMART-1 array, the coherence is reduced in a high frequency range even on the hard rock.
2. The spatial variation of the ground motion reduces the response of secondary systems with high frequency. This may lead to more rational seismic design practice for equipmental components of nuclear power plant systems.

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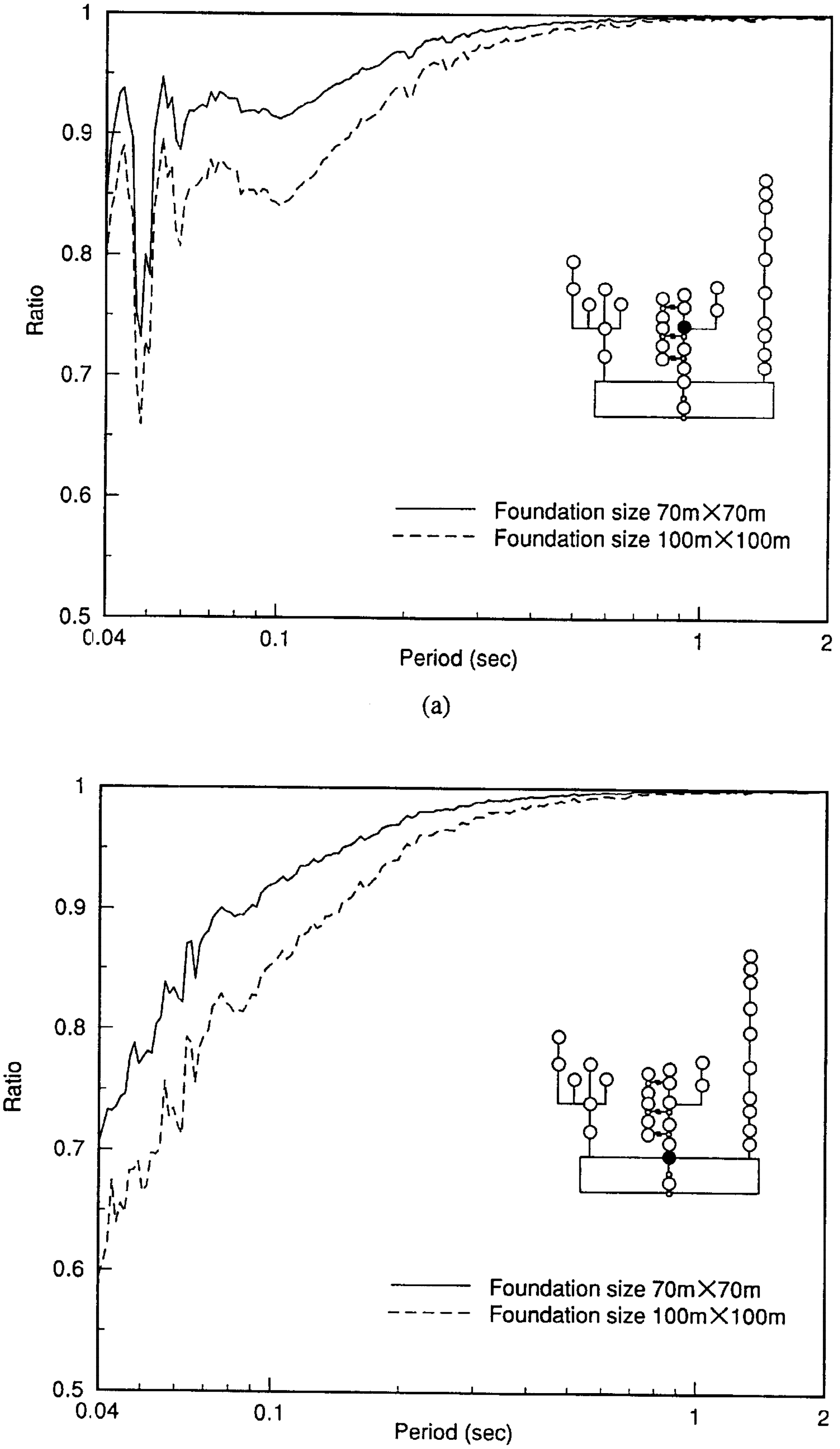

(a)

(b)

Fig. 6. Reduction ratio