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REGIONALITY OF LONG-PERIOD GROUND MOTION USING JMA STRONG MOTION DISPLACEMENT RECORDS

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ABSTRACT

The amplification factor of long-period (2 to 20 sec) ground motion for each seismic source zone in Japan was determined by taking the ratio of observed to theoretical spectra, using strong motion displacement records of Japan Meteorological Agency. As a result, it is shown that the amplification factor differs with each zone, remarkably. It is possible to estimate the acceleration spectrum for an earthquake with arbitrary magnitude and epicentral distance, by the product of the theoretical acceleration spectrum and the amplification factor. The predicted spectrum for the earthquake of maximum expected magnitude in each zone gives the information on the seismic hazard of long-period ground motions.

KEYWORDS

Long-period ground motion; regionality; seismic source zone; amplification factor; prediction of spectrum.

INTRODUCTION

In the 1983 Nihonkai-Chubu earthquake, oil tanks were damaged by liquid sloshing caused by long-period ground motions. In particular, liquid in oil tanks overflowed at Niigata during this earthquake, in spite of an epicentral distance of about 300 km. Kudo and Sakaue(1984) found that earthquake ground motion at a period of about 10 sec at Niigata was about ten times as strong as the one at Aikawa, whose location is much the same as Niigata. This fact means that the regionality of long-period ground motion is very important.

Since the generation of liquid sloshing is explained by resonance between liquid in a tank and ground motions, it is very important, in predicting damage of oil tanks, to evaluate ground motions in the long-period range, including the natural period of liquid sloshing of a large oil storage tank.

In this paper, the amplification factor of long-period ground motion from 2 to 20 sec for each seismic source zone is determined for Tokyo, Niigata, and Osaka by comparing observed with theoretical spectra,using strong motion records. Then, the acceleration spectrum is estimated for the earthquake with maximum expected magnitude and average epicentral distance, and the hazard on the long-period ground motion is also presented.

FRAMEWORK TO EVALUATE REGIONALITY

Here, the acceleration spectrum is treated, because the sloshing wave height is approximately given as a function of acceleration spectrum. The strong motion in a long-period range is mainly composed of surface waves. Using the normal mode theory and Haskell-Savage source model, Kudo(1989) derived the semi-empirical equation to express the acceleration spectrum in terms of only earthquake magnitude(M) and epicentral distance(r) as follows.

$$Fo(T) = 4.8 \cdot As(T) 10^{0.5M-2} \exp(-\alpha(T)r)/r^{0.5} \qquad (T \leqq Tc), \qquad (1)$$

$$Fo(T) = 4.8 \cdot As(T) 10^{0.5M-2} \exp(-\alpha(T)r) \cdot (Tc/T)^{2}/r^{0.5} \qquad (T \geqq Tc), \qquad (2)$$

$$\log \alpha(T) = 9.11/T - 4.26, \qquad (3)$$

$$Tc = 10^{0.5M-2.4}, \qquad (4)$$

where Fo(T) and As(T) are the observed spectrum and amplification factor as a function of period(T). Above equations were derived on the basis of several assumptions such as taking only Love wave into consideration. When As(T)=1, Fo(T) is a standard acceleration spectrum. Ratio of the observed to the standard spectrum gives an amplification factor for each earthquake.

It is often observed that seismic waveform from earthquakes in a seismic source zone is very similar withone another as shown in Fig.1. In this case, two events occurred in the Izu region, southwest of Tokyo, but had different magnitude. This suggests that the effects of source mechanism and path on the ground motion are almost same, and that it is possible to explain the ground motion characteristics at an observation point for a seismic source zone, by only considering the scaling law of earthquake.

Thus, the final amplification factor at an observation site for each seismic source zone, which correspondsto the regionality, is obtained by taking average of each amplification factor. The acceleration spectrum can be predicted using this amplification factor for the earthquake with any magnitude and epicentral distance. Accordingly, the spectral level can be evaluated for the greatest earthquake in each seismic zone, and the most harmful seismic source zone to the site can be also identified.

DATA

Japan Meteorological Agency (JMA) had operated the displacement type strong motion seismographs for about forty years in Japan. Since the natural period of the seismometer is about six second, it is competent to record long-period ground motions. As these seismograms are analogue records, these should be digitized. Then, a system to digitize seismograms semi-automatically was developed, out of necessity for analyzing a great deal of seismograms. This system is composed of a personal computer and an image scanner. Principle in digitizing is very simple, that is, the digitization is performed by tracing the darkest point in the area with density over the threshold on each line scanned by the image scanner. Time needed in digitizing a three component record is about 30 minutes.

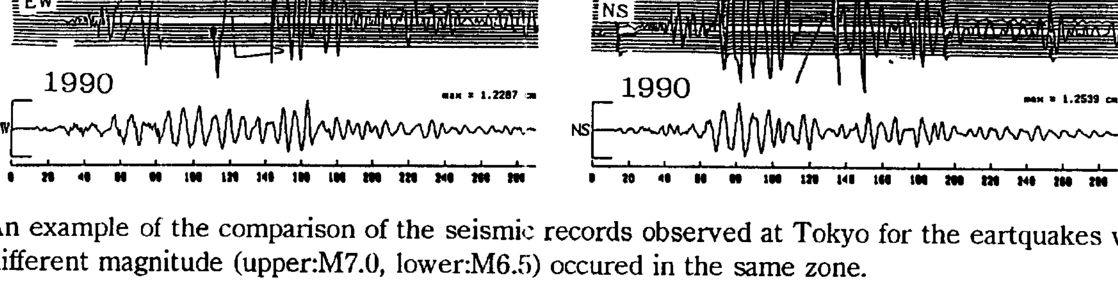

Fig.1 An example of the comparison of the seismic records observed at Tokyo for the eartquakes with different magnitude (upper:M7.0, lower:M6.5) occured in the same zone.

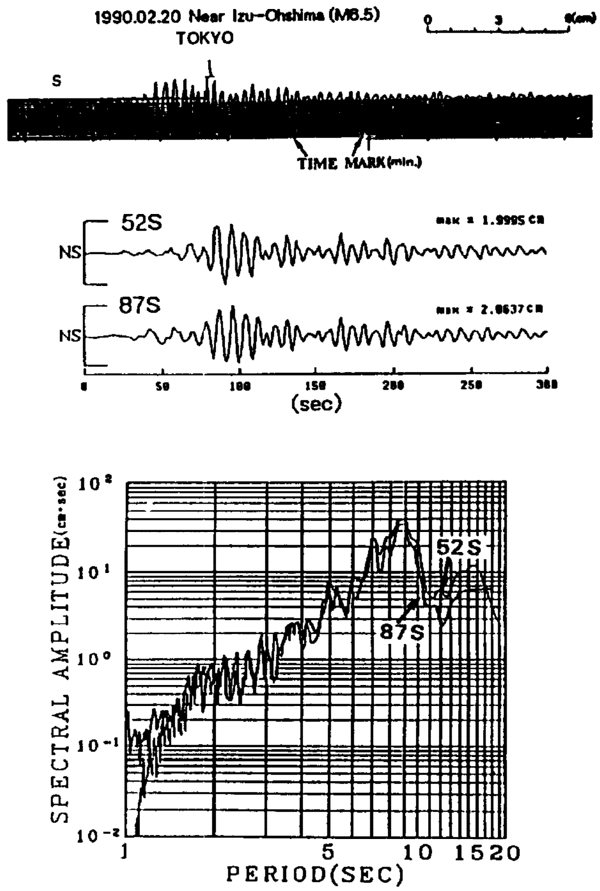

Fig.2 Comparison of the waveform and its Fourier spectrum by JMA strong motion displacement seismograph(52S) with those by the broad band digital seismograph(87S) for the 1990 Izu–Oshima Kinkai earthquake.

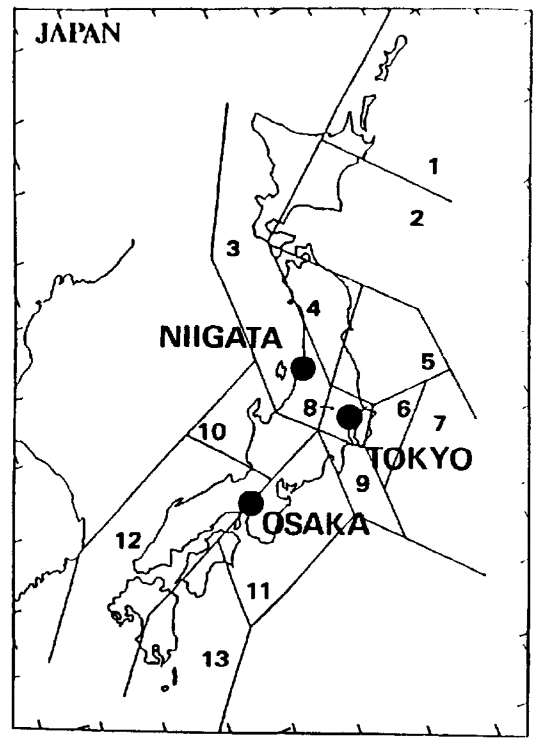

Fig.3 Seismic source zones in Japan and JMA local observatories treated in this study.

In order to evaluate the accuracy of digitization, data digitized by this system was corrected for the instrumental response, and compared with the broad band digital records observed at the same site. The comparison showed a good agreement as shown in Fig.2.

Analyzed seismic records were obtained at JMA local stations in Tokyo, Niigata, and Osaka, near where many oil storage tanks exist. Figure 3 shows thirteen seismic source zones proposed by JMA(1990). Fifty–eight records at Tokyo, eighty–six at Niigata, and sixty–six at Osaka were classified by these zones.

RESULTS AND DISCUSSION

Figure 4 shows the estimated amplification factor for Tokyo, Niigata, and Osaka. From this figure, it is obvious that the amplification factor depends on the period. Furthermore, it can be seen that the amplification factor differs with both the seismic source zone and the observation site. In general, the amplification factor of Niigata is the largest and more than one in the period of 2 to 20 sec. The amplification factor of Osaka is below one in the most of periods and seismic zones. It is worthy of our notice that the amplification factor is very large for zone 9 in the period of about 8 to 9 sec at Tokyo, and that the one of Niigata is about eight at a period about 10 sec.

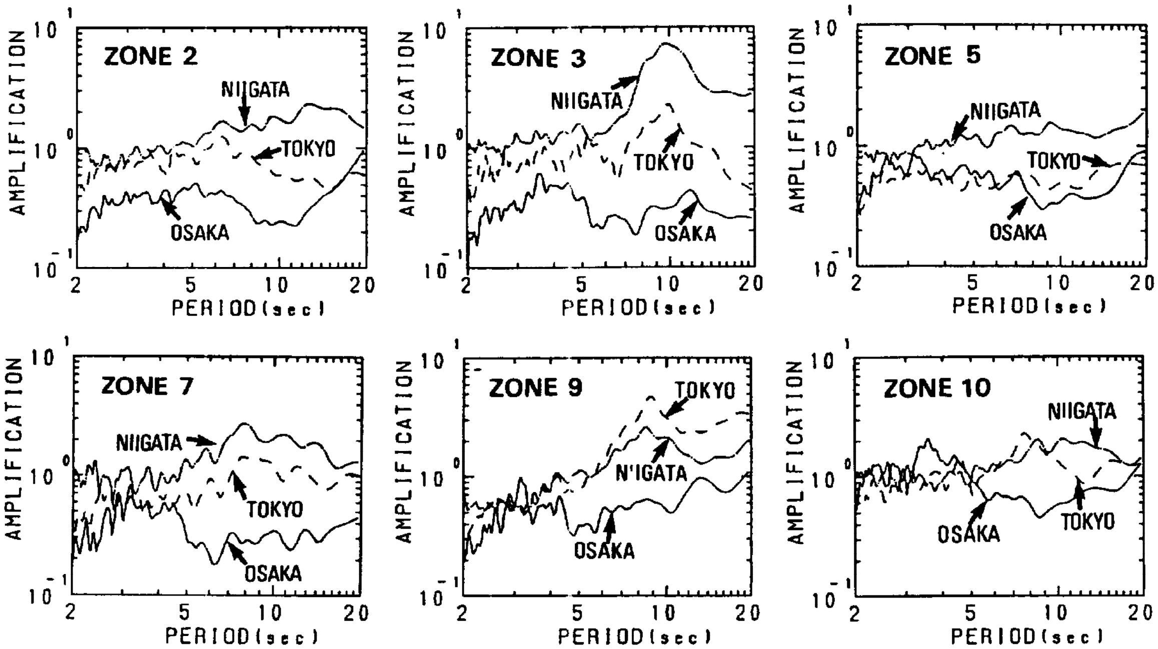

Fig.4 Amplification factors as a function of period for Tokyo, Niigata, and Osaka in each seismic source zone.

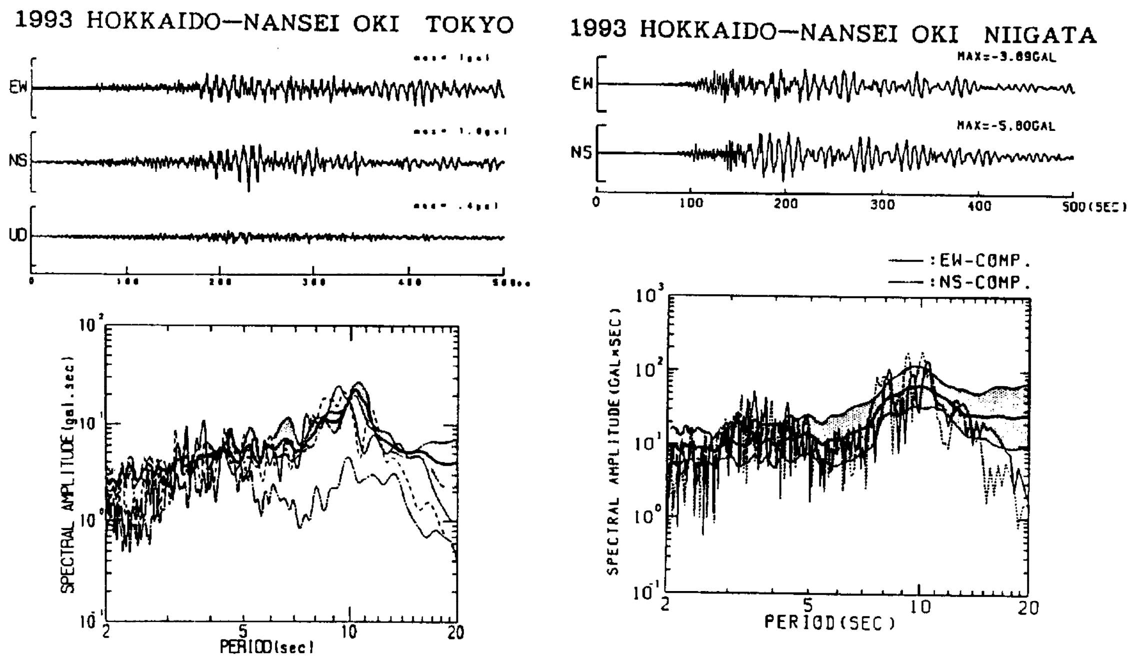

Fig.6 Comparison between the predicted (thick line) and observed acceleration spectrum at Tokyo (left side) and Niigata (right side) for the 1993 Hokkaido–Nansei Oki earthquake. Shaded are is the standard deviation bounds of the predicted spectrum.

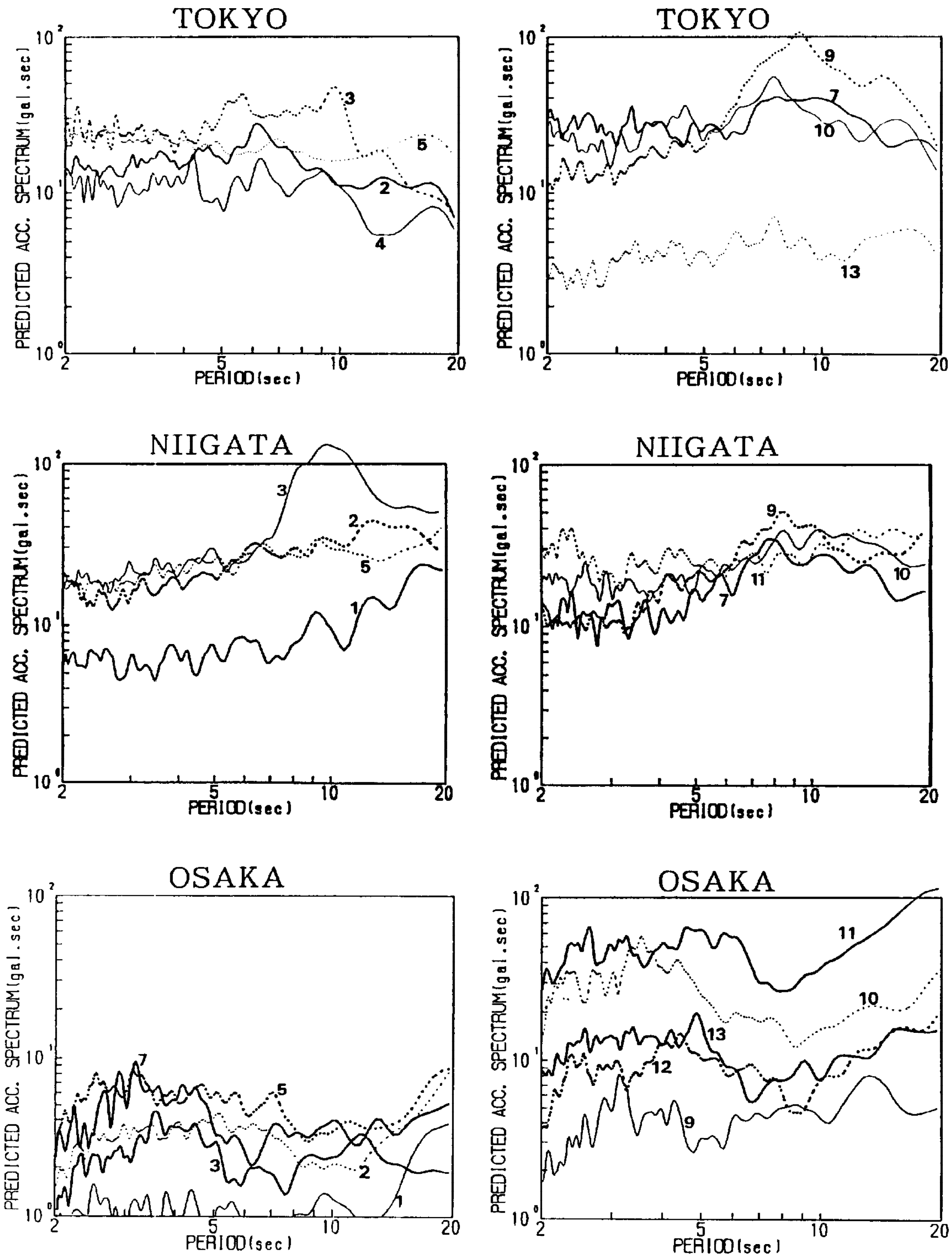

Fig 5. Predicted acceleration spectra for the largest earthquake in each seismic source zone at Tokyo, Niigata, and Osaka.

Using this amplification factor, it is possible to estimate the acceleration spectrum for the earthquake witharbitrary earthquake magnitude and epicentral distance. Figure 5 shows the predicted acceleration spectra for the earthquake with the maximum expected magnitude in each seismic zone supposed by Hagiwara(1991). According to the regulation concerned with the liquid sloshing of oil storage tank, acceleration spectral level is about 100 gal·sec. Thus, there is the possibility of overflow of the liquid in a tank whose natural period of sloshing is about 8 sec in Tokyo for zone 9 and is about 10 sec in Niigata for zone 3. In Osaka, meanwhile, there is few possibility of overflow. In practice, the observed sloshing height is no more than 1 meter in Osaka area during the 1995 Hyougo–ken Nanbu earthquake.

In order to confirm the accuracy of prediction, the predicted spectra were compared with the observed spectra. Figure 6 shows the comparison of spectra for the 1993 Hokkaido–Nansei Oki earthquake at Tokyo and Niigata. Close agreement between the observed and predicted spectrum is obtained. This guarantees the accuracy of the estimated amplification factor.

To conclude, the regionality of long–period ground motion varies very much with both site and seismic source zone, and the above mentioned procedure is useful to evaluate the seismic hazard for long–period ground motions.

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