Tentative Design Response Spectrum for Seismically Isolated FBR

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Introduction

In the present paper, the tentative velocity response spectrum formulated as input seismic motion for studying the following three items concerning verification test on seismically isolated FBR is discussed.

(1) Determination of the scale of seismically isolated element testing apparatus and the dimensions of seismically isolated elements
(2) Study on seismically isolating method and seismically isolated structure
(3) Verification test on seismically isolated FBR

Basic conditions for formulating the tentative velocity response spectrum (h=5%)

The velocity response spectrum for tentative study formulated this time is not aimed at a specific point but is based on a general design condition that seismically isolated FBR is constructed on the bedrock in any area of Japan. The following four conditions are established to formulate the tentative velocity response spectrum.

(1) Regarding a slightly long-period seismic motion (T = 2 ~10 sec.), the one which give an impact of the largest class possible in Japan shall be subjected to evaluation. Limit values are not to be evaluated.
(2) The subject point shall satisfy the siting conditions for light-water type power reactors in Japan as a general rule, provided that points which have an accumulation layer of several thousand meters and cause a slightly long-period seismic motion to be amplified extremely shall be excluded.
(3) For short-period domain, the existing spectrum used in light-water type power reactors shall be respected.
(4) The vertical motion established with respect to the horizontal motion shall be defined by the ratio of amplitude to the horizontal motion.

Method for formulating the tentative velocity response spectrum

Seismic scale subject to evaluation

Looking at the distribution of seismic damages in Japan, earthquakes of M8 class occur off the coast of Sanriku and along the Nankai trough, and many of them occur in the sea areas more than 50 km away off the coast of the Pacific Ocean. Also, from the seismo-tectonics map (Omote's map) for extreme earthquakes, all of M8 class earthquakes occur off the coast of the Pacific Ocean, except some parts in Central Japan. Unless special cases are considered, therefore, discussion here is carried out on the velocity response spectrum for tentative study aimed at the earthquake of M8 with epicentral distance of 50 km.

Method for estimating the velocity response spectrum

To estimate the tentative spectrum for M8 and epicentral distance (Δ) of 50 km, the results of the following methods were currently judged in general.

(1) Using bedrock accelerograms for strong motion earthquakes, a record of moderate earthquake of about 50 km in epicenter distance is compensated into a record of M8 earthquake by a simple method for evaluation.
(2) The pseudo velocity response spectrum in the bedrock accelerogram is subjected to regression analysis at M and Δ, and evaluation is performed by extrapolating the empirical equation thus obtained.
(3) Evaluation is performed by a simple semi-empirical equation using a fault model.
(4) Evaluation is performed by a semi-empirical equation relating love wave in accordance with the normal mode theory.
(5) As for the short-period domain, evaluation is performed by the existing spectrum used in the light-water type power reactor.

Results of estimation by the tentative spectrum

Results of estimation using the accelerogram on bedrock

With respect to the accelerogram (88 components) of M6 or more, about 50 km in epicentral distance and 60 km or less in hypocenter depth obtained on the bedrock (Vs= 700-1800m/sec), the spectrum amplitude of each observation record was compensated into equivalence of M8 using the coefficient (γ) expressed by equation (1), and the result thus obtained is shown in Fig. 2 together with the mean and standard deviation.

$$\gamma=10^{\Delta M} \tag{1}$$

Equation (1) considers only the term relating to amplitude and magnitude from the equation for determining the magnitude adopted by the Japanese Meteorological Agency (JMA), and an appropriate result can be obtained for the spectrum amplitude in the neighborhood of 5 seconds in period. The result was about 40 kine in mean value and about 60 kine in mean value + standard deviation ($+\sigma$) in the neighborhood of 5 seconds in period. In Fig. 3, regression analysis was made at M and Δ on 88 pseudo velocity response spectrums (h=5%) obtained from the above-mentioned observation record, and from the regression equation thus obtained the mean spectrum at M8 and 50 km in epicentral distance and its standard deviation were determined. Equation (2) was used as the regression equation.

$$\log Sv\ (T)=a(T)M-(b(T)+m\ \log R)+c(T)+\Sigma di\,(T) \tag{2}$$

Here, if the body wave is assumed, then $m = 1$, and R refers to hypocentral distance X; if the surface wave is assumed, then $m = 1/2$ and R refers to hypocentral distance Δ. Also, for differential factor versus observation point, Σdi (T), difference in conditions at observation points was taken into consideration. Sv is a velocity response spectrum.

From this, the result obtained by the regression equation is about 40 kine in mean value, and about 70 kine if standard deviation ($+\sigma$) is also considered.

Results of estimation by the semi-empirical equation based on fault model

Ishida[1,3] proposed a method for calculating the seismic motion in bedrock by using a low pass-filter which compensates the short-period spectrum because the theoretical seismic motion spectrum based on a simple fault model (Haskell model) underestimates the amplitude of the short-period seismic motion spectrum. Moreover, as this method required many fault parameter, an evaluation equation was proposed by reducing the number of parameters and using magnitude (M), hypocentral distance (X) and stress drop ($\Delta\sigma$) as variables. According to this proposal, the acceleration Fourier spectrum in seismic bedrock can be expressed by the following equation:

$$\ddot{U}(\omega) \sim \left\{(18 \times 10^{0.5M-2}/X)/A\ (T)\right\} \cdot \exp(-\omega X/2VQ) \tag{3}$$

Where, vs: shear wave velocity; Q: value Q which represents a decay drop in the propagation path; A(T): low-pass filter shown by the following equation:

$$\left.\begin{aligned} A(T) &= aT/(1+aT) \\ a &= 0.023\Delta\sigma + 0.22 \end{aligned}\right\} \tag{4}$$

The acceleration Fourier spectrum thus obtained is determined by a seismic moment in the long-period domain and by a stress drop in the short-period domain, as its characteristic.

Kudo[2] assumed as d = 10 km the mid-point depth of the underground structural model and fault width obtained by blasting test at Yumenoshima in Tokyo and determined the semi-empirical equation of acceleration spectrum intensity $\ddot{U}(\omega)$ (cm/s) on the ground surface against surface wave as shown below, with M and epicentral distance Δ as parameters.

$$\ddot{U}(\omega) \sim 7.2 \times 10^{0.5M-2}\sqrt{\Delta} \tag{5}$$

Evaluation by the latter for M8 and epicentral distance 50 km shows about 100 kine. However, considering the fact that this empirical equation relates to Tokyo which has a thick accumulation layer and that the evaluation corresponds to the response spectrum of h = 0%, there is a strong possibility that this evaluation is considerably large. On the other hand, the former evaluates the incident wave equivalent to seismic bedrock to be 13 kine and assumes the amplification ratio of incident wave to amplitude to be about 4 times, thus expecting a seismic motion of 72 kine.

Tentative velocity response spectrum

The results of these studies are summarized in Fig. 4. Based on these results, the tentative value is set at 100 kine within the range of 2 to 10 seconds in period, with engineering judgment considered. It is evident from the figure that this value is almost equal to a velocity response spectrum value (mean value + 2σ) which is the analytical result based on the seismic observation record. As for short-period domain, the spectrum including a short-period domain and slightly long-period domain is shown in Fig. 5 which adopts existing light-water type power reactor standards. As is clear from this figure, there is a large difference in the spectrum level at a period of 2 seconds. Because of this, both spectrums will be tentatively used as shown by the dotted line. Meanwhile, for reference, eternal observation records of Japan Sea Central Earthquake (Mj = 7.7) which occurred in 1983 and spectrums of La Union records on Mexican Earthquake (Ms = 8.1) which occurred in 1985 are shown in the figure.

Estimation of vertical motion velocity response spectrum

The vertical motion velocity response spectrum (h = 5%) is defined by its ratio to the horizontal motion velocity response spectrum (h = 5%). In Fig. 6, the ratio (vertical motion spectrum/horizontal motion spectrum) and the value$\pm$ are shown. The seismic motion record is the same data-set as that used in estimating the tentative horizontal motion velocity response spectrum. The indicated ratio of the vertical motion spectrum to the horizontal motion spectrum is about 0.6 when the period is 2 seconds of more, and in the short-period domain that value is increasing gradually.

Here, considering the fact that attention is paid to the spectrum amplitude in a slightly long-period spectrum, the ratio of the vertical motion spectrum to the horizontal motion spectrum was tentatively set at 0.6.

Conclusion

The velocity response spectrum of a slightly long-period earthquake studied this time was tentatively set at 100 kine in the range of about 2 to 10 seconds in period. This is the result obtained by considering collectively the analytical results of seismic observation records on bedrock, the results of evaluation using a simple fault model (M = 8.0, epicentral distance = 50 kine) and the results of evaluation by a prediction equation concerning the spectrum amplitude of love wave (M = 8.0, epicentral distance = 50 km).

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References

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2) K. Kudo: A study on the estimation of surface wave related to the long-period structure. 5JCEE, 1982.
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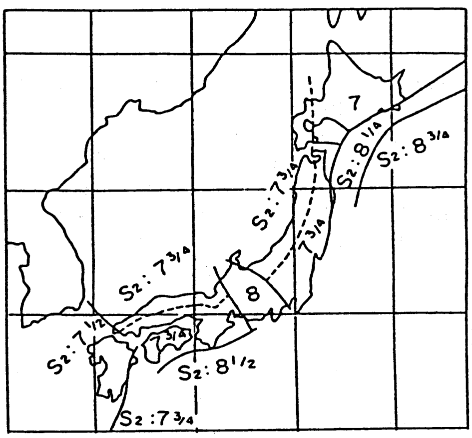

Fig.1 Map on Seismotectonics (Omote's map). Numeral of the figure indicated the extream magnitude which is expected to occure.

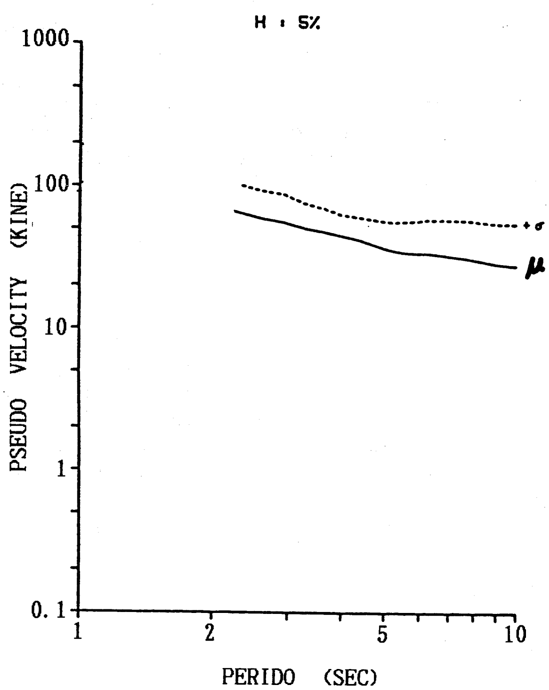

Fig.2 Pseudo velocity response spectra (mean(μ), mean + standard deviation σ) corrected by $\gamma = 10^{\Delta M}$ (eq.1).

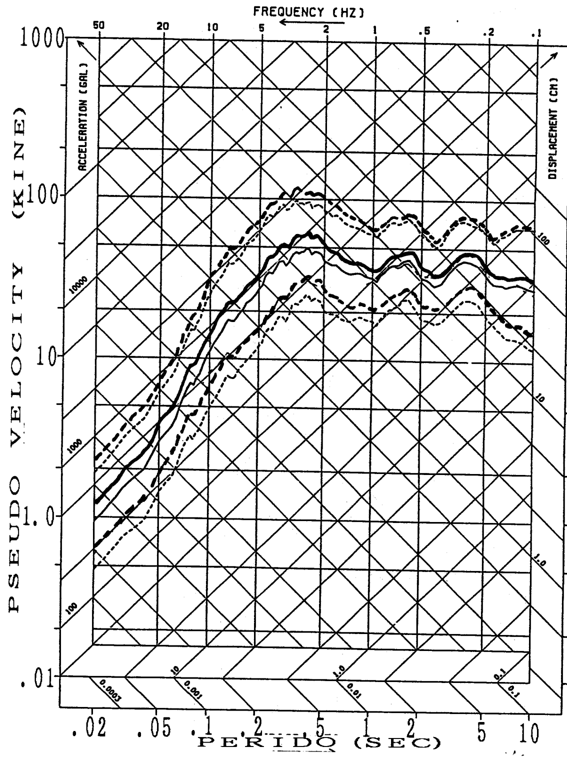

Fig.3 Pseudo velocity response spectra (mean (μ), mean + standard deviation (σ) estimated by regression analysis (eq.2). Thick lines are the results for m=1 (eq.2). Fine lines are the results for m=1 (eq.2).

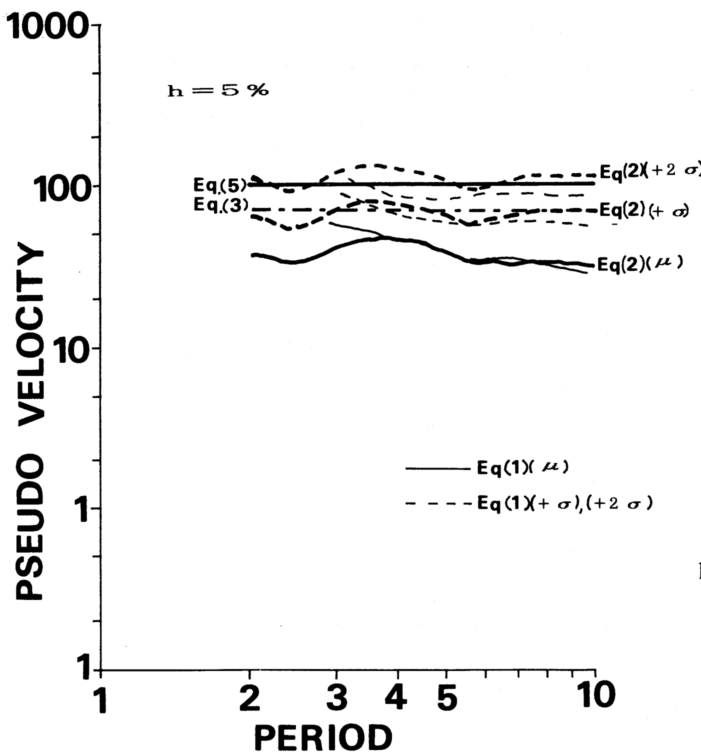

Fig.4 Comparisons of the results obtained verious methods (eqs.1 ~ 5).

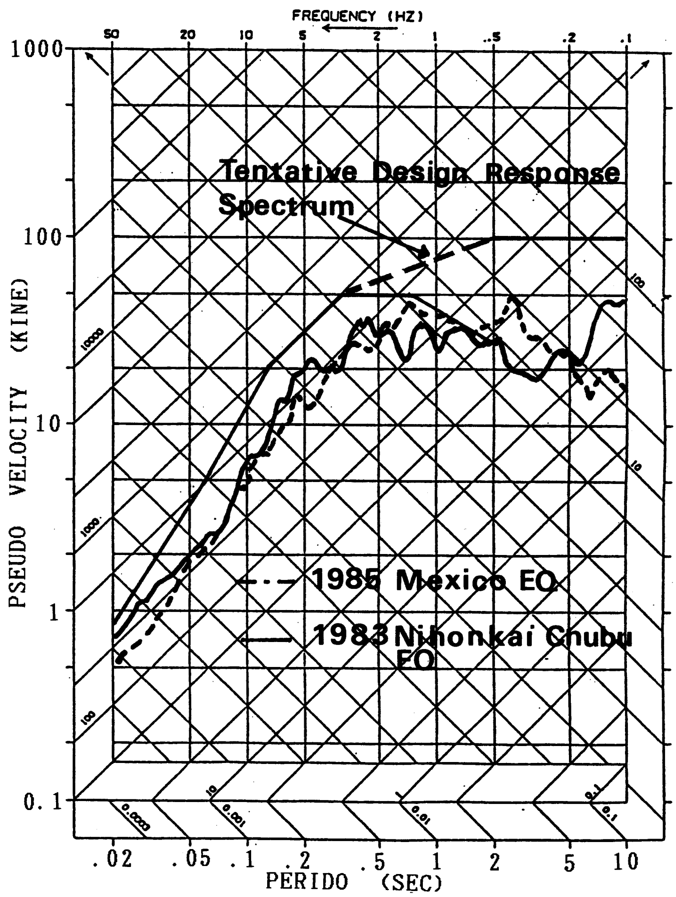

Fig.5 Tentative design base velocity response spectrum (h=5%) and the comparisons of observed response spectra of 1983 Nihonkai-Chubu earthquake and 1985 Mexico earthquake.

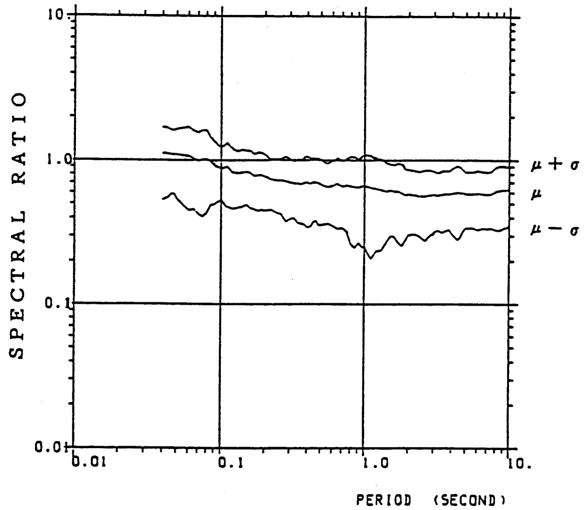

Fig.6 Spectral ratio (vertical / horizontal).