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ATTENUATION RELATIONS OF ACCELERATION RESPONSE SPECTRA AT DAM FOUNDATIONS IN JAPAN

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SUMMARY

The evaluations of design earthquakes and characterization of earthquake ground motions are important aspects of the seismic analysis and design of dams. Earthquake ground motions are affected by earthquake source mechanisms, source-to-transmission path properties, and site conditions. There are three basic approaches to developing site-specific earthquake motions: theoretical, semi-empirical and empirical. Although the first two approaches, i.e. theoretical and semi-empirical approaches are rapidly evolving, their results should still be examined based on the empirical relationships for design use. As for the last approach, the attenuation relations for response spectra of ground motions developed by some empirical ways contribute greatly to the rough estimation of possible ground motions.

The Ministry of Land, Infrastructure and Transport (former, the Ministry of Construction) has conducted earthquake-motion observation at dam sites since 1957. With the Kobe Earthquake in 1995 as a turning point, the Ministry decided to strengthen the seismograph installation at all of jurisdictional dams for the intensification of the emergency management. The accumulation of earthquake records at dam sites, that is very valuable for the evaluation of seismic motion at dam sites, have greatly advanced in this decade.

We have developed attenuation relations on ground motions at dam sites by the statistical analysis using the abovementioned records compilation[1]. The earthquakes used for the analysis have magnitude larger than 5.0, epicentral distance less than 200km, and hypocentral depth less than 130km. All accelerograms were recorded at the dams on rock foundations. They were recorded at 91 dam sites and for 63 earthquakes. The attenuation relations were developed for the three types of earthquakes, namely, the shallow crustal, inter-plate, and deep intra-slab earthquakes.

In this paper, the influence of magnitude, distance measure, and the earthquake depth upon the spectrum characteristis is analyzed. Acceleration time histories measured in the Tokachi-oki Earthquake are compared with acceleration response spectrum presumed from attenuation relations .Based on these

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attenuation relations, we discuss the characteristics of ground motions at rock foundations for existing dams in Japan.

INTRODUCTION

For seismic design of dams, it is an important subject to presume the earthquake motions expected at dam sites. There are three basic approaches to develop site-specific earthquake motions: theoretical, semi-empirical and empirical. In the theoretical approach, the site strong ground motions are predicted from the calculation of wave propagation in the three dimensional elastic media. In the semi-empirical approach, the scaling similarity law of large and small earthquakes is assumed, and site specific ground motions are estimated from the recorded small earthquakes by using empirical Green’s function. Although the first two approaches, i.e. theoretical and semi-empirical approaches are rapidly evolving, their results should still be examined base on the empirical relationships for design use.

In the empirical approach, the site specific motions are estimated from attenuation relations which the earthquake magnitude and site-to-source distance.

In this paper, we describe the attenuation relations developed from results of the regression of the acceleration spectra on the rock foundations at dam sites

THE DATASETS OF EARTHQUAKE RECORDS

From the datasets of the acceleration records observed at dam under the jurisdiction of the Ministry of Land, Infrastructure and Transport, the data in and after 1974 were extracted and used in this study[2]. The earthquakes used for the analysis have the magnitude of larger than 5.0, epicentral distance less than 200km, and hypocentral depth less than 130km. They were recorded at 91 dam sites and for 63 earthquakes. The location of dam sites, and epicenter of the earthquakes are shown in Figure 1, and 2, respectively. The Japan Meteorological Agency(JMA) magnitude, hypocentral depth, and epicentral distance of the earthquakes used in the analysis are illustrated in Fig. 3.

Most acceleration instruments are placed at the inspection gallery at the lowest elevation in case of concrete dams, and at the bottom inspection gallery in case of embankment dams. All foundations consist of rocks, not including soils. However, some foundations consist of soft rock of the late Neogene, Tertiary. The longitudinal wave speed Vp is considered to be 1.8 - 4.5 km/s for the bedrock of many concrete dams, 1.5 - 3.0 km/s for the bedrock of embankment dams. Assuming the value of V_p/V_s to be about 2.0, the average shear wave velocity V_s of the foundations for dams is supposed to be from 0.7 to 1.5km/s.

The earthquakes used for analysis were classified into three types: earthquakes which occur in the shallow crust, earthquakes in inter-plate of the subduction zone, and earthquakes which occur in the intra-slab of dipping ocean plate away from the ocean trench as shown in Table-1.

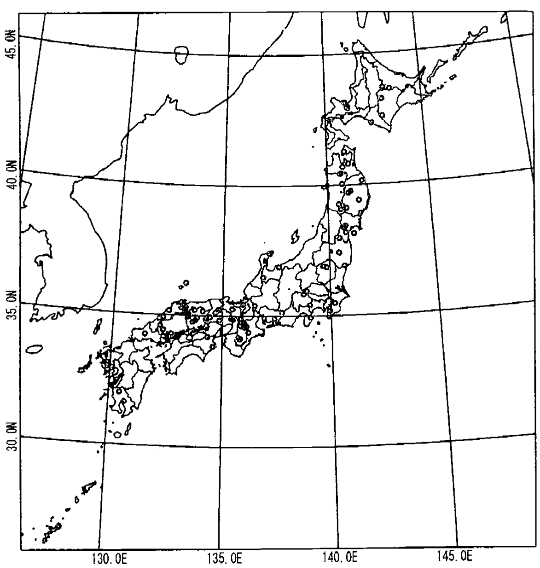

Fig.1 Location of a dam site which data used in regression analysis

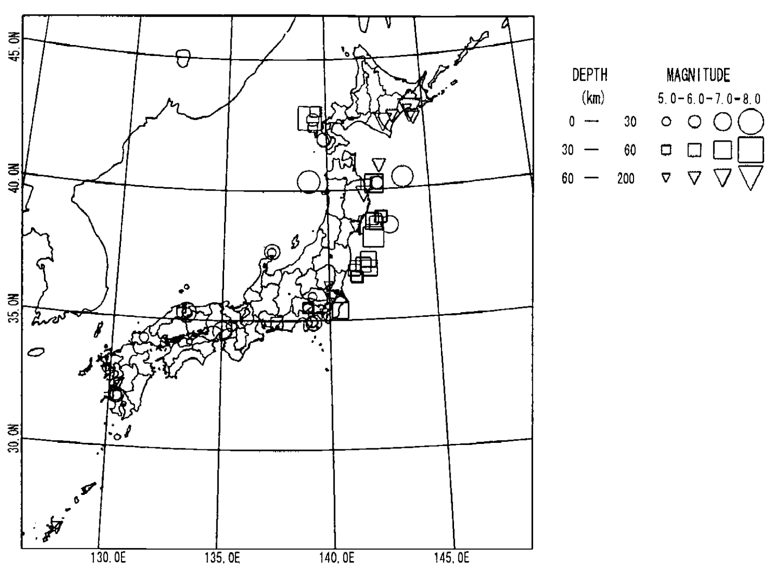

Fig.2 Distribution of epicenters used for regression analysis

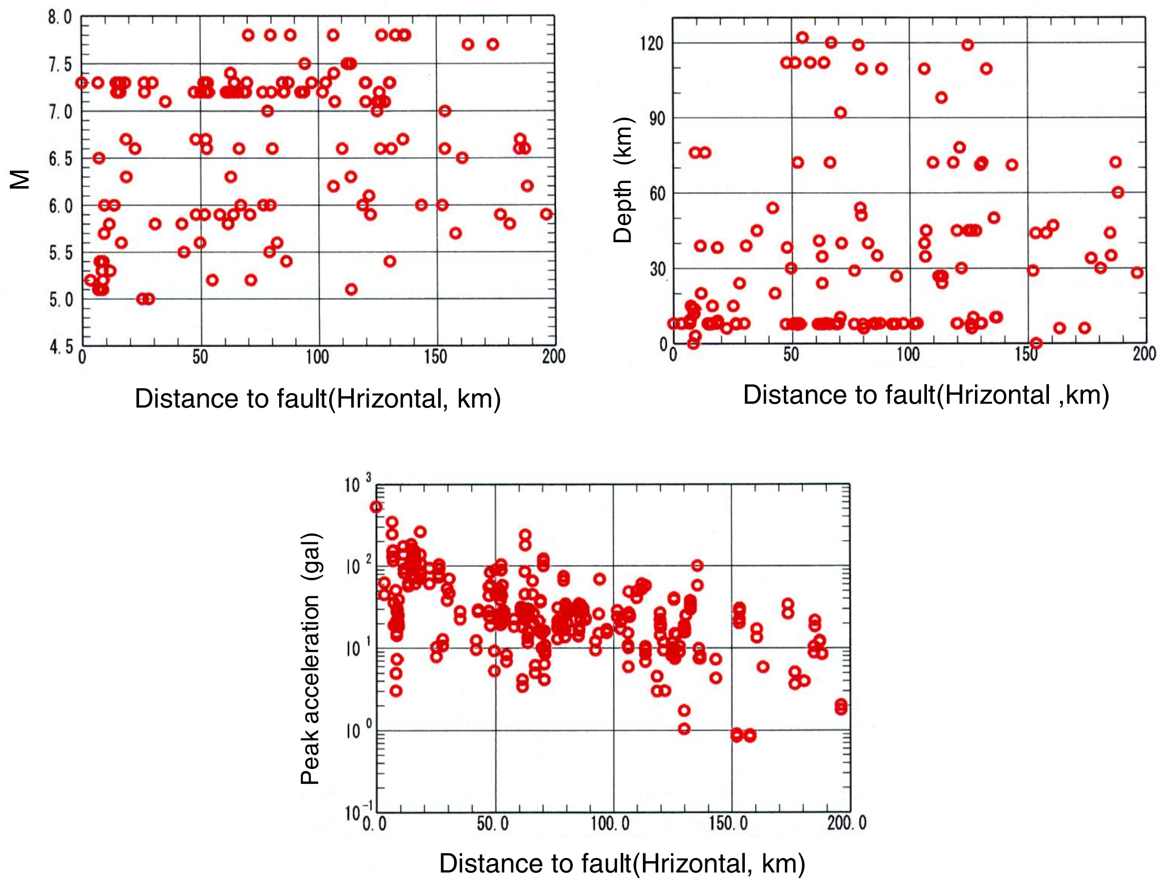

Fig.3 JMA Magnitude, depth, and PGA with distance used for regression analysis

Table-1 Types of earthquake

Type	Number of Recordings	Remarks
Shallow crustal	81 sets, 175 components	Epicenters are located in the inland of Japan with the shallow hypocentral depth.
Inter-plate	29 sets, 55 components	Epicenters are located in the ocean with hypocentral depth less than 60km.
Deep Intra-slab	29 sets, 63 components	Epicenters are located in the inland with hypocentral depth greater than 60km.

REGRESSION MODEL

Two regression models in which two distance measured the shortest distance and equivalent hypocentral distance are used, were developed. Of all 63 earthquakes, 12 earthquakes have been determined for their fault source mechanism.

In developing the functional form of the regression equation, we used the following:

$$\log SA(T) = Cm(T)M + Ch(T)Hc - Cd(T)\log(R + 0.334\exp(0.653M)) + Co(T) \quad \cdots(1)$$

where T is the period, $SA(T)$ is the spectrum of average of horizontal two components, M is the JMA magnitude, Hc=H for H<100km, Hc=100 for H>100km, H is the epicentral depth, and R is the shortest distance to the fault plane. The term 0.334exp(0.653M) is employed for limiting the value of $SA(T)$ when R approaches to zero, and is the same one with Annaka et. al. (1997)[3]. Cm, Ch, Cd, Co are coefficients determined from the regression analysis.

We also used another regression form of the following:

$$\log SA(T) = Cm(T)M + Ch(T)Hc - Cd(T)Xeq - \log Xeq + Co(T) \quad \cdots\cdots\cdots(2)$$

where Xeq is the equivalent epicentral distance.

We used the Joyner and Boore one-step most likelihood method(1993)[4] for the regression analysis.

ATTENUATION OF RESPONSE SPECTRA

We developed the attenuation relations for the acceleration response spectrum of 5% damping. Fig.4 shows the regression coefficients with the period. These coefficients are obtained from all the earthquakes average regardless of earthquake type.

To evaluate, differences due to earthquake types, the correction factor is obtained as the ratio of average to each earthquake type. Correction factors are illustrated in Fig. 5 for each earthquake type. The factor for deep intra-slab is close to the average of 1.0. The factor for shallow crustal is the smallest. And the factor for Inter-plate type is the largest.

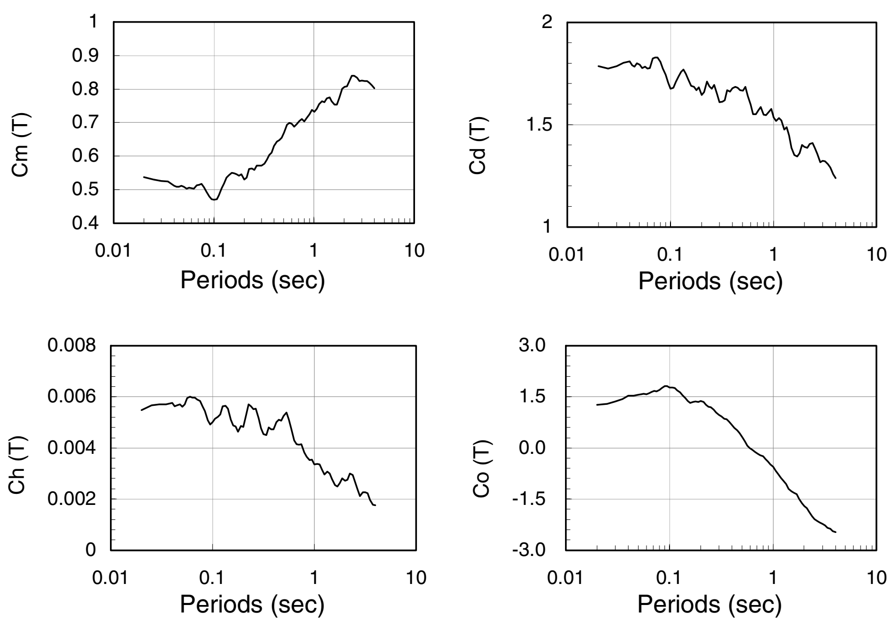

Fig.4 The regression coefficient for the shortest distance equation

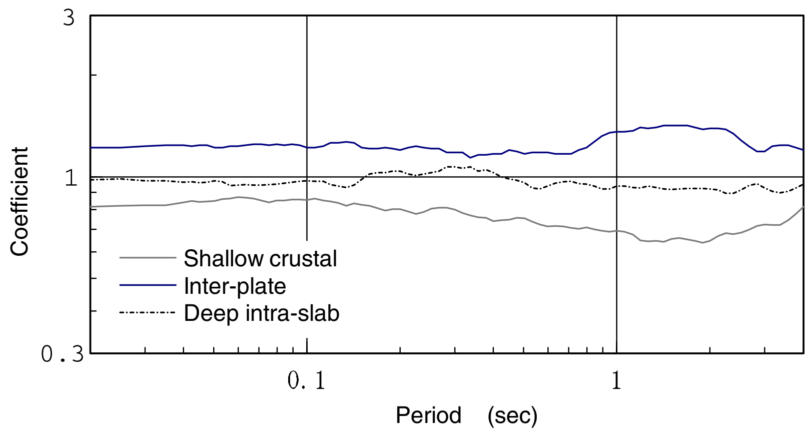

Fig.5 Correction factor for reach earthquake type

EARTHQUAKE MOTION CHARACTERISTIC OF ROCK FOUNDATION

Comparison of the spectra for each earthquake type is shown in Figs. 6 - 8. Fig. 6 is for the shallow crustal earthquakes, and Fig. 7 for the inter-plate earthquakes, Fig. 8 for the intra-slab earthquakes. In the Figs. 6 - 8 the “a” and “b” show the effects of magnitude, distance and depth, respectively. In Fig. 8, “b” shows the effect of distance when the depth is equal to the distance. Fig. 9 shows effect of earthquake types on the acceleration responses.

In Figs. 6a, 7a and 8a although it is very common, the larger a magnitude is, the larger the spectrum amplitude especially in long period range are.

In Figs. 6b, 7b and 8b, the distance has, of course, great effects on the spectrum amplitude, but, small effects on the natural period.

In Fig.9, corresponding to explanation about regression coefficient in the precvious section, the amplitude of a response spectrum is the largest for Inter-plate earthquakes, and one for shallow crustal earthquakes is the smallest. The response spectrum of shallow crustal earthquake and deep intra-slab in the almost same natural period, in the case of intra-plate earthquaske, natural period becomes a slightly longer period.

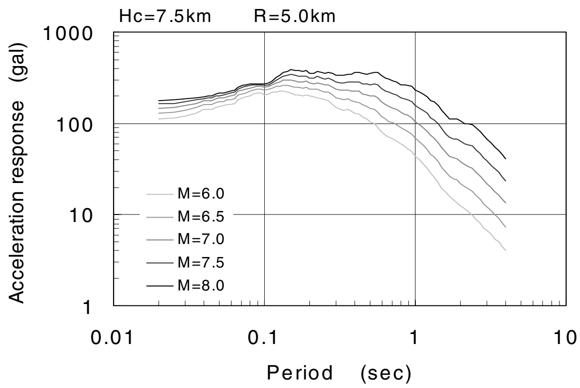

Fig.6a Effect of magnitude
(Shallow crustal,Hc=7.5km,R=5km)

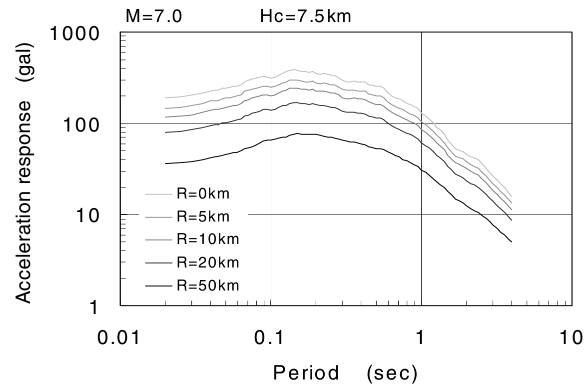

Fig.6b Effect of distance
(Shallow crustal,M=7.0,Hc=7.5km)

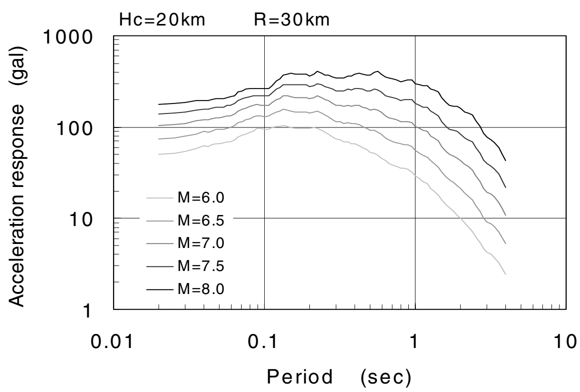

Fig.7a Effect of magnitude
(Inter-plate, Hc=20km,R=30km)

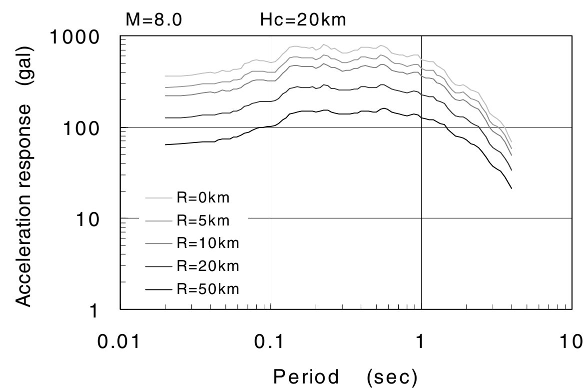

Fig.7b Effect of distance
(Inter-plate, M=8.0km,Hc=20km)

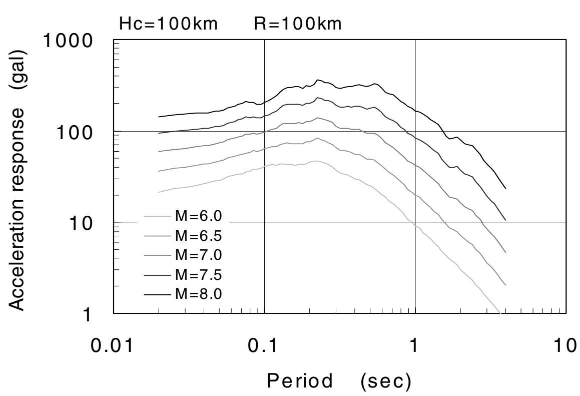

Fig.8a Effect of magnitude
(Deep intra-slab,Hc=100km,R=100km)

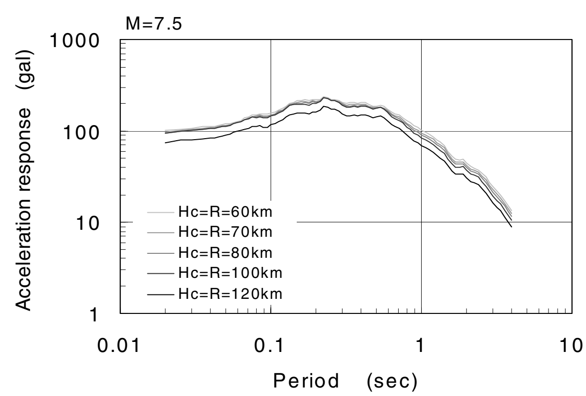

Fig.8b Effect of distance
(Deep intra-slab,M=7.5km)

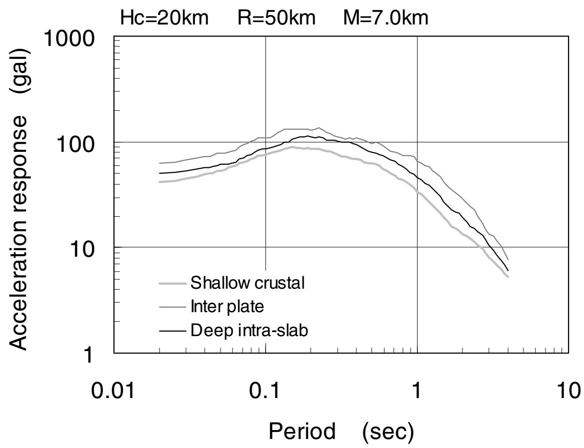

Fig.9a Effect of earthquake type
(Hc=20km,R=50km, M=7.0)

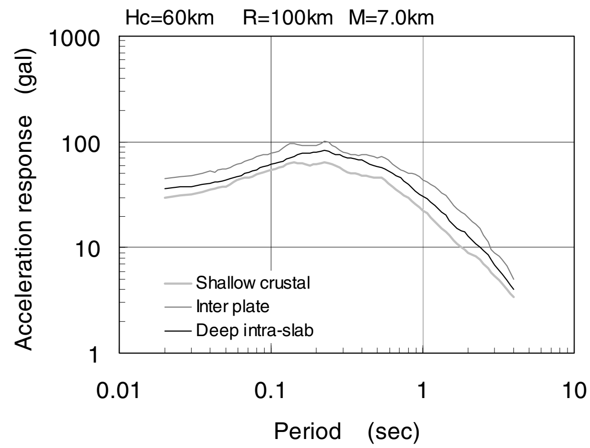

Fig.9b Effect of earthquake type
(Hc=100km,R=100km, M=7.0)

COMPARISON WITH MOST RECENT EVENT

On September 26,2003, the Tokati-oki earthquake occurred in Northern Japan. It is a typical inter-plate reverse earthquake with the magnitude of 8.0. The ruptured fault plane is 86km long, and 83km wide, and dips about 20 degrees to the North-West. The event occurred after we had developed the attenuation relations discussed above.

Fig. 10a ,b are time histories acceleration obtained at two dam sites during the Tokachi-oki Earthquake. Fig. 11 shows location of fault and strong motion stations. Fig. 12 shows the dislocation model of Tokachi-oki Earthquake and Table 2 shows the fault parameters. The parameters of dislocation model were determined in the Geographical Survey Institute (GSI).

Fig. 12 shows comparison results of response spectra. Simulated response spectra are diagramed with total of four lines. They are the shortest distance equation (Equation-1) and an equivalent hypocentral distance equation (Equation-2), and are two levels of an average and average + standard deviation further.

The acceleration records are settled between the average of the computed response spectrum, and average + standard deviation, and are well in agreement with the average of a response spectrum.

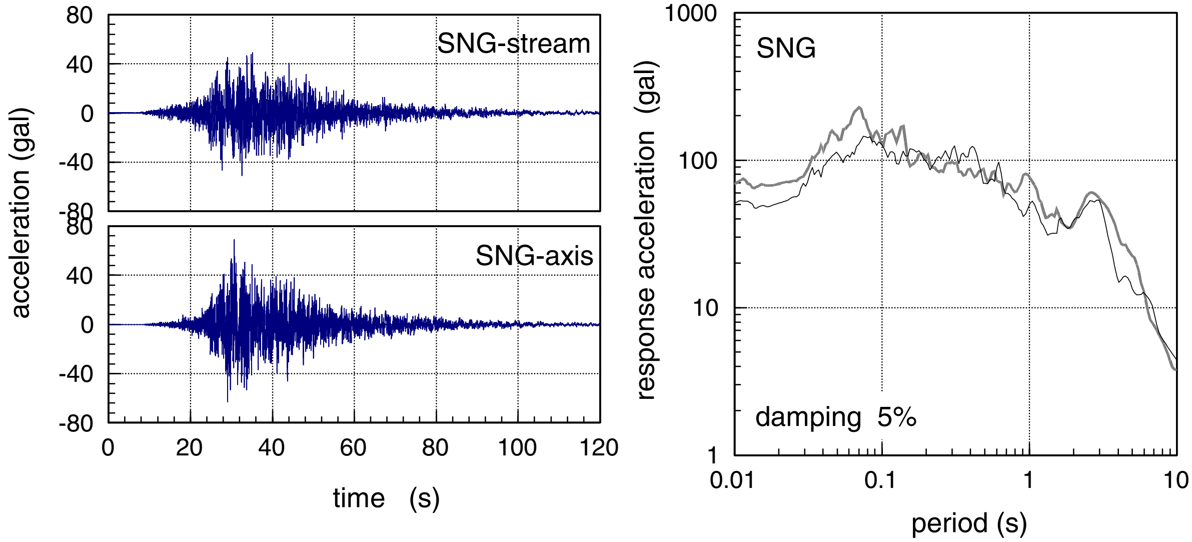

Fig. 10a Acceleration time history and acceleration spectra
of the observed waves (SNG)

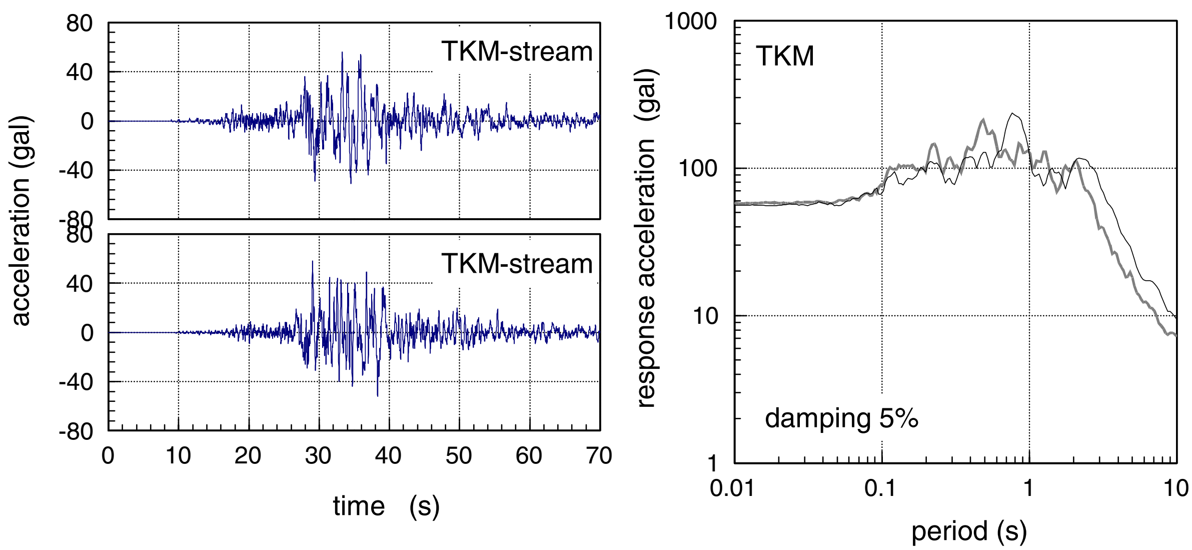

Fig. 10b Acceleration time history and acceleration spectra
of the observed waves (TKM)

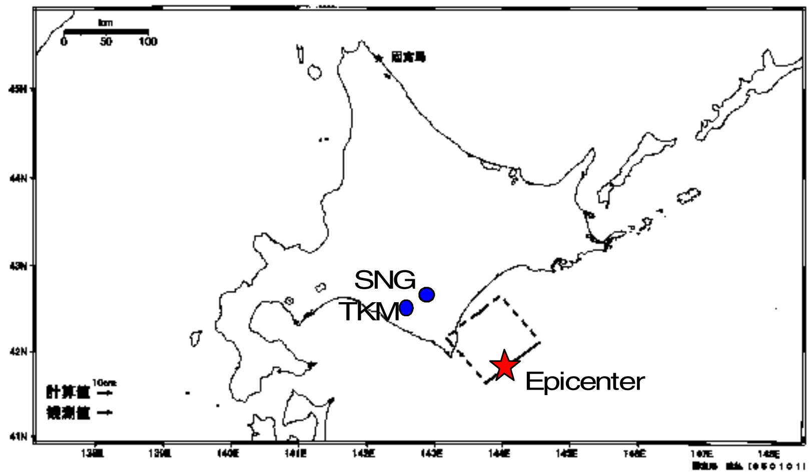

Fig.11 Location of fault and strong motion stations

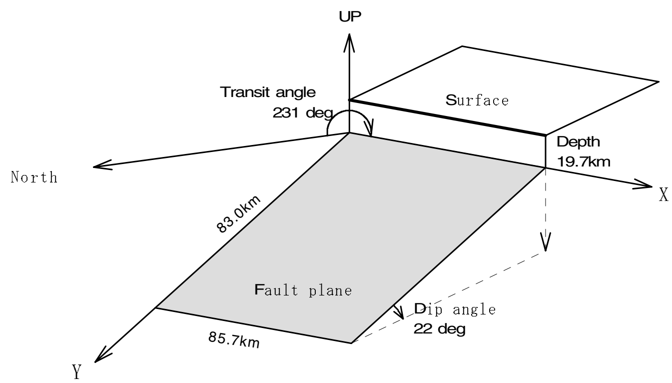

Fig. 12 Source fault model proposed
for 2003 Tokachi-oki Earthquake

Table-2 The fault parameters
(2003,Tokachi-oki Earthquake)

Parameters	source fault model
Magnitude	8.0
Site location	42.12 N , 144.55 E
Earthquake focal depth	35.2 km
Length	85.7 km
Width	83.0 km
Depth	19.7 km
Transit angle	231 deg
Dip angle	22 deg

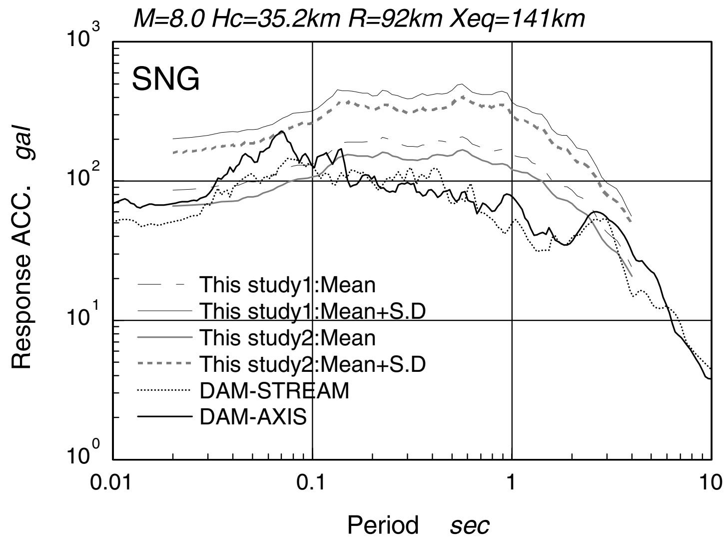

Fig. 13a Acceleration response spectra of the simulated wave compare with those of the observed ones

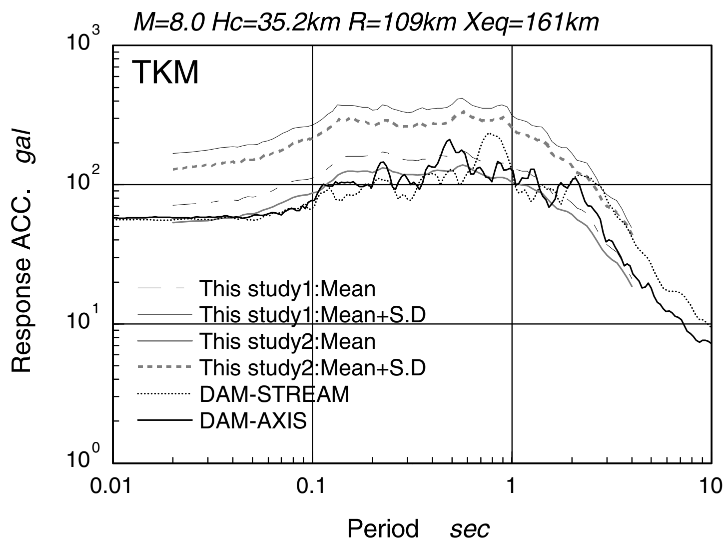

Fig. 13b Acceleration response spectra of the simulated wave compare with those of the observed ones.

CONCLUSION

This paper described attenuation relations for horizontal spectral acceleration obtained from the data set of the earthquake motions recorded at the dam sites in Japan. These equations were developed corresponding to the three earthquake types, i.e. shallow crustal, inter-plate, deep intra-slab, taking account of the differences of characteristics of seismic motions due to their types.

The adaptability of the attenuation equation to evaluate the earthquake motion on the rock foundation was shown using records obtained during recent large earthquake with the magnitude of 8.

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