Characteristics of Seismic Vibrations on Rock Foundation of Dam Sites and Attenuation Relationships of Acceleration Response Spectra at Dam Foundations in Japan

by

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ABSTRACT

Japan has repeatedly experienced big earthquakes since ancient times. With the Kobe Earthquake as a turning point, the Ministry of Land, Infrastructure and Transport (MLIT) decided to install seismographs at all of jurisdictional dams for the intensification of the emergency management. The installation of seismographs was completed by the ends of the year 2000, the MLIT for 413 dams and it became possible to observe earthquake motions with high density at dam sites. Furthermore, the MLIT has been networking seismographs of dams and building the system, which can collect the information immediately after the occurrence of earthquake. In this paper, we introduce and discuss a vibration characteristic of dam foundation and a presumed attenuation equation of acceleration response spectra based on observed waveform records at dam sites.

KEY WORDS: Dam, Attenuation relationship, Characteristics of Seismic Vibration, Rock Foundation

1. INTRODUCTION

Japan is a country where many earthquakes occur, and has repeatedly experienced the big earthquakes in the past also in the world. Seismographs were installed at the Sarutani dam in 1957. It was the first case of seismograph instration among dams which the MLIT superintends, and the earthquake observation at the dam sites by the MLIT (former the Ministry of Construction) was started from that time. The Kobe Earthquake in 1995, Although the strong motion attacked many dams, some dams for power generation and city water uses near the earthquake fault had no seismographs, and earthquake data were not obtained. From such experience, the MLIT considers as the purpose of the emergency management in case of an earthquake and for the improvement of seismic design. After the Kobe Earthquake, new installation of seismographs to dams that had not got seismographs was started, and the renewal from analog-type seismographs to digital-type ones was speeded up. Installation to all 413 dams under the jurisdictional of the MLIT was completed by 2000.

Furthermore, The networking of seismographs of dams under the jurisdictional of the MLIT and Water Resources Development Public Corp. (WARDEC) has promoted, and construction of new system has been advanced for collecting of the information of dams immediately after an earthquake is occurs.
In 2001. the Public Works Research Institute

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(PWRI) published two Technical Memorandums of PWRI about earthquake data collecting at dam sites. One [1] is about the information of seismograph installation and another [2] is about the observed data by March, 2000.

2. EARTHQUAKE MOTION CHARACTERISTICS OF ROCK FOUNDATION DAM SITES

2.1 The Range of Data

The data for analysis was acceleration data observed at the base of dam and free field near dam sites. Where, a dam base means the lowest gallery of a concrete dam, and the gallery beneath the impervious zone of a rock-fill dam. 143 sets (a horizontal direction 286, the vertical direction 143) of observation waveform records extracted from conditions of magnitude five or more, and epicentral distance to less than 200km. All waveform records were observed on the dam sites on rock foundation and the S-wave velocity of the foundation is considered to be faster than about 1000 m/s.

2.2 Analysis of Observation Waveform Records

Earthquakes were classified into three types (Inter-plate, Intra-palte, and Crustal) according to the locations of the earthquake focus. The Inter-plate earthquake is defined as the earthquake which epicenter is located in the ocean area and focus depth of is less than 60km, Iintra-plate type as the earthquake which occurs in inland area, and the Crustal type as the earthquake which occurs in the depths of 60km or more and epicenter is located in inland. Table 1 shows a list of number of earthquakes of 143 by three earthquake types.

Fig. 1 shows relationship of the magnitude, the hypocenter depth, and distance. Where, distance means the shortest distance to a fault line. The used data distributed in wide range. Although there are many earthquake records of Intra-plate type, mainly those are from the Western Tottori earthquake in 2000.

Fig. 2 shows relationship of the maximum acceleration of wave form records and distance. The presumed results from the distance attenuation relationship proposed by Fukushima et al. [3] are also shown. This distance attenuation relationship was drawn from the data recorded on firm ground. As compared with the presumed value by Fukushima et al., the acceleration at the dam site tends to be small, especially in the case of large magnitude.

Fig. 3 shows the relationship of the maximum acceleration of a horizontal direction and the vertical direction. The ratio is relatively low for the large horizontal acceleration. The effect of the earthquake types is not clear.

Fig.4 shows the correlation of the predominant period of the response spectra in the stream direction, and dam axis direction. From this figure, the predominant periods are not different for the stream direction and dam-axis direction, and are concentrated at around 0.2 seconds.

Fig.5 (a) shows the ratio of acceleration response spectrum of the stream direction and the dam-axis direction, Fig.5 (b) shows the ratio of average response spectrum of horizontal directions and response spectrum of the vertical direction. From Fig. 5 (a), the clear difference of the ratio about two horizontal components by three earthquake types isn’t seen and the ratio seems to be constant over the all periods. From Fig. 5 (b), on the other hand, there is a tendency that the ratio about horizontal and vertical components is fluctuated over around 0.15 seconds

Fig.6 shows average acceleration response spectrum, and Fig.7 shows average acceleration response magnification spectrum by 3 magnitude ranges, that is, 5.5, 6.5 and 7.5, in the case of a intra-plate type. The data used for these figures are about earthquakes of focus depth of 0-20km and distance of 0-40km. The larger the magnitude range is, the larger the period where the magnification spectrum meets the peak value is.

3 Attenuation Relationships of Acceleration Response Spectrum

For the seismic design of dams, it is important to regulate a design earthquake motion properly. Several attenuation equations of maximum acceleration or acceleration response spectra have been proposed [3][4][5][6] and utilized practically. But, those equations are for soil foundation or soft rock foundations. The new equation about attenuation relationship [7] of response spectrum presumption for rock foundation at dam was proposed recently using acceleration data accumulated in the NILIM. The equation was made based on the regression model proposed by Annaka et al. [5]. Equation (1) is a form of the regression model.

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

Where, *T* means periods, *SA(T)* means average response spectrum of 2 horizontal directions, *M* means magnitude by definition of the Japan Meteorological Agency(JMA), *Hc* means the depth of center of fault plane, and *R* means the nearest distance to fault. The parameter of 0.334exp (0.653*M*) expresses the saturation of *SA(T)* when *R* approaches zero. *Cm*, *Ch*, *Cd* and *Co* are coefficients drawn by statistics processing from the acceleration waveform records observed at dam sites.

Fig.8(a) shows coefficients of *Cm, Ch, Cd, Co* in Equation (1) and Fig.8 (b) shows compensation factors for three earthquake types. Fig.9 shows the examples of presumed response spectrum *SA(T)*. The relationship between the presumed response spectrum *SA(T)* and magnitude *M* is shown in Fig. 10(a) and the relationship between the presumed response spectrum *SA(T)* and the distance *R* for specific periods, i.e. 0. 02, 0.2, 0.5, 1.0, 2.0, 4.0 sec.

4. CONCLUSION

The attenuation relationship of acceleration response spectrum for dam was introduced. The MLIT is planning revise the standard of an seismic design for dams. and presumed education introduced here is expected as one of technique to determine the design earthquake motion in seismic.We continue to collect earthquake data at dam sitesand set will improve the attenuation formula.

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Table .1 Number of earthquakes clarified in 143 is classified for three earthquake type.

EQ Type	TOTAL
Intra-plate	88
Inter-plate	26
Crustal	29
TOTAL	143

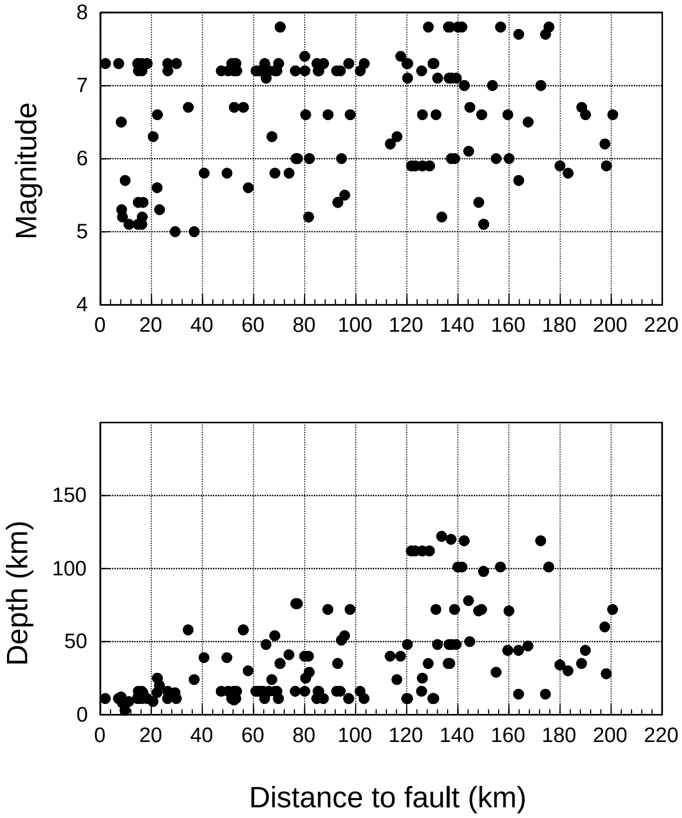


Fig.1 Relationship of magnitude, hypocenter depth with, and distance

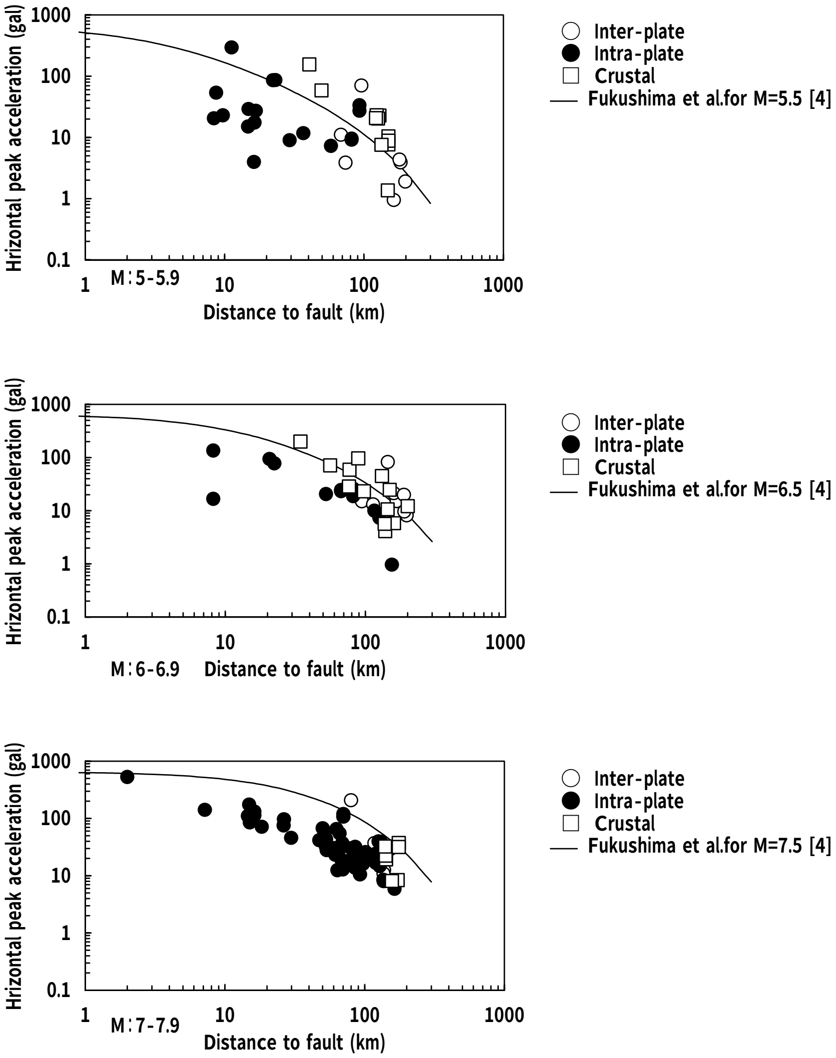


Fig .2 Relationship of maximum acceleration with distance for three magnitude ranges

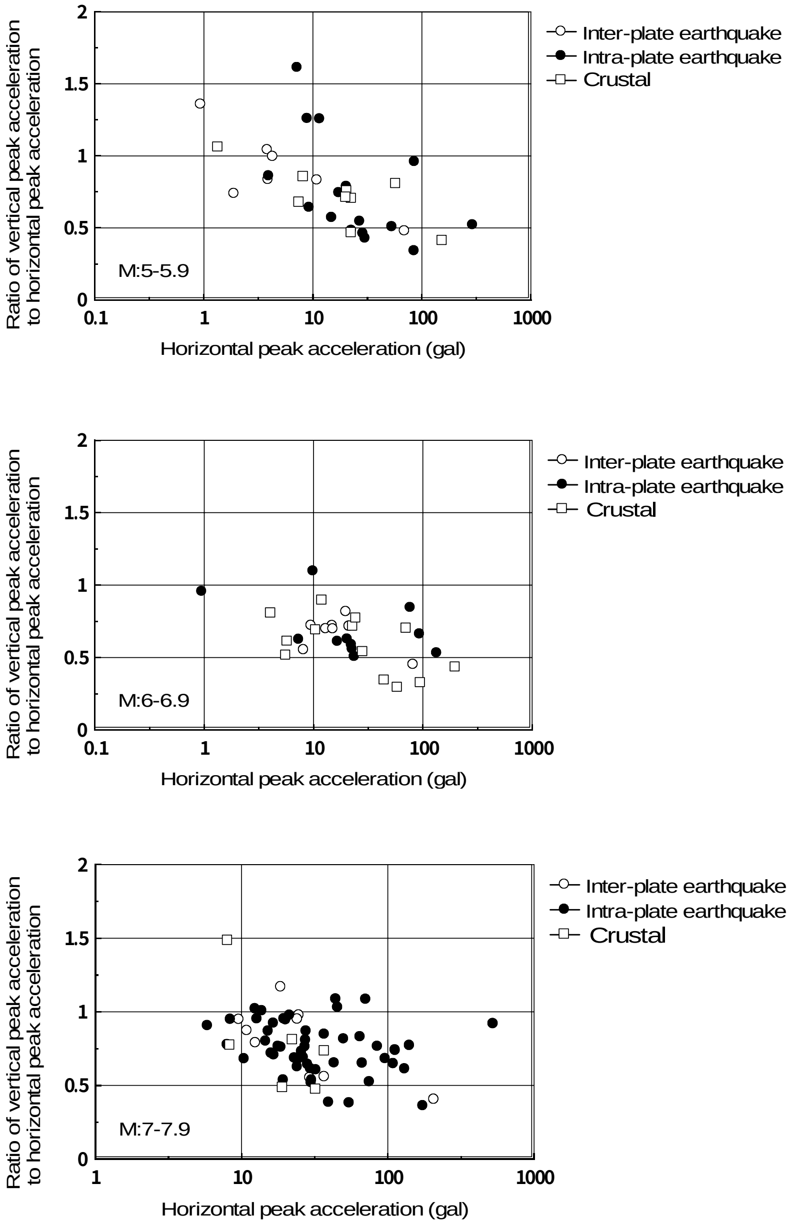


Fig .3 Relationship between maximum horizontal acceleration
and ratio of maximum horizontal acceleration

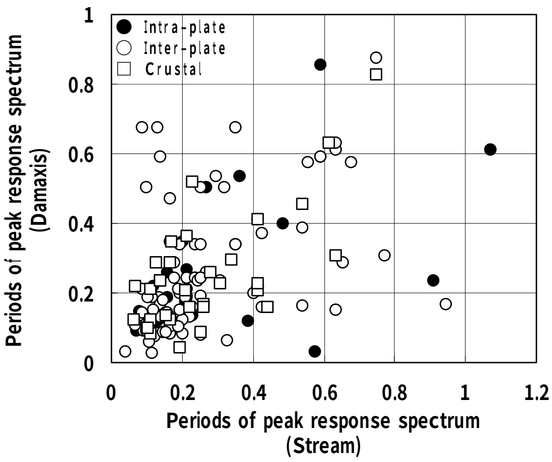
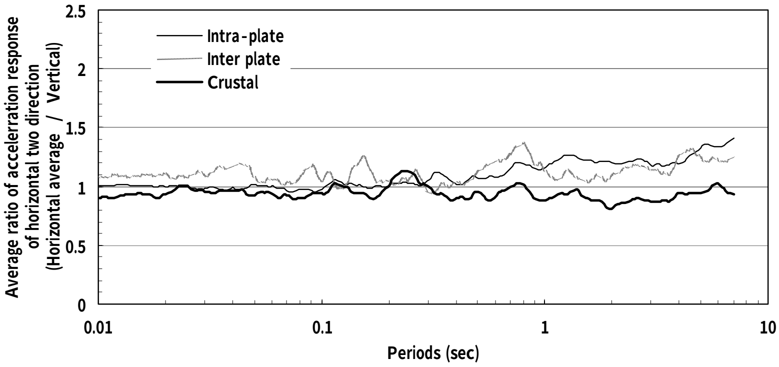
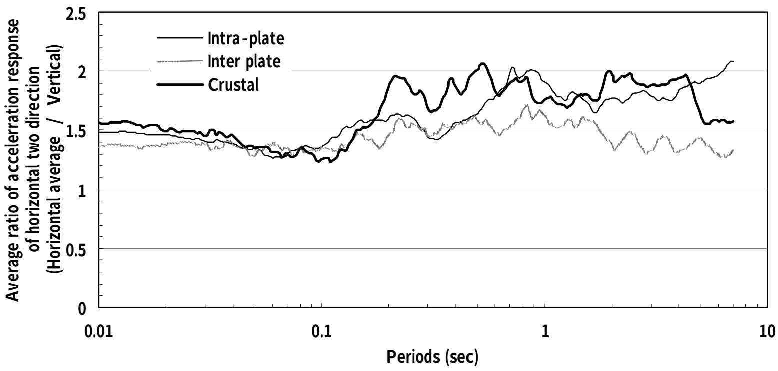


Fig.4 Correlation of predominant periods acceleration response for spectra for stream direction and dam-axis-direction



(a) Ratio of acceleration response of dam-axis direction and stream direction



(b) Ratio of acceleration response of horizontal direction and vertical direction

Fig.5 Ratio of acceleration response spectrum

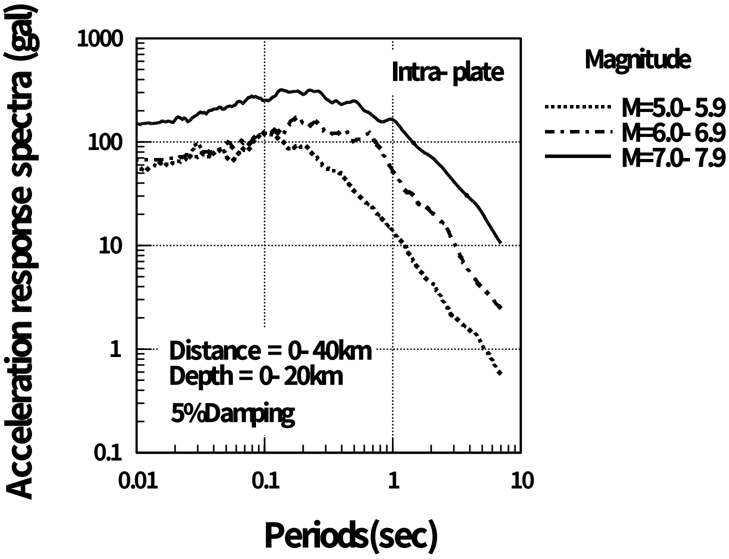


Fig 6 Relationship of average acceleration response spectrum by three magnitude ranges

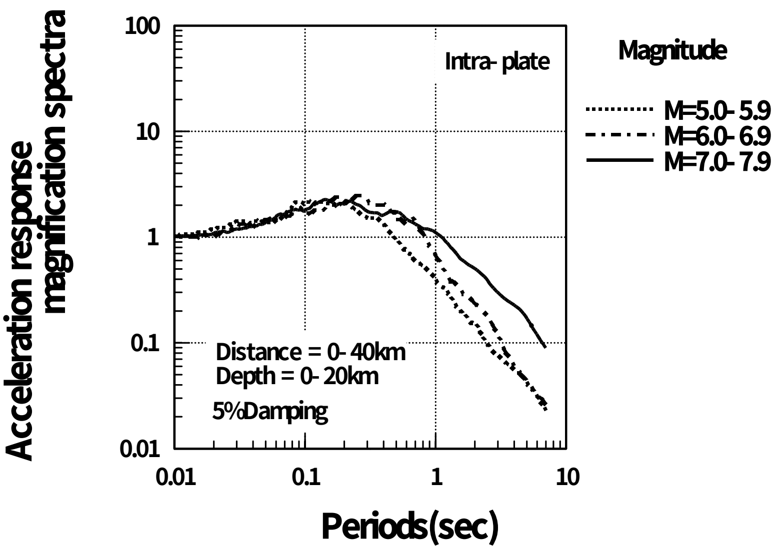
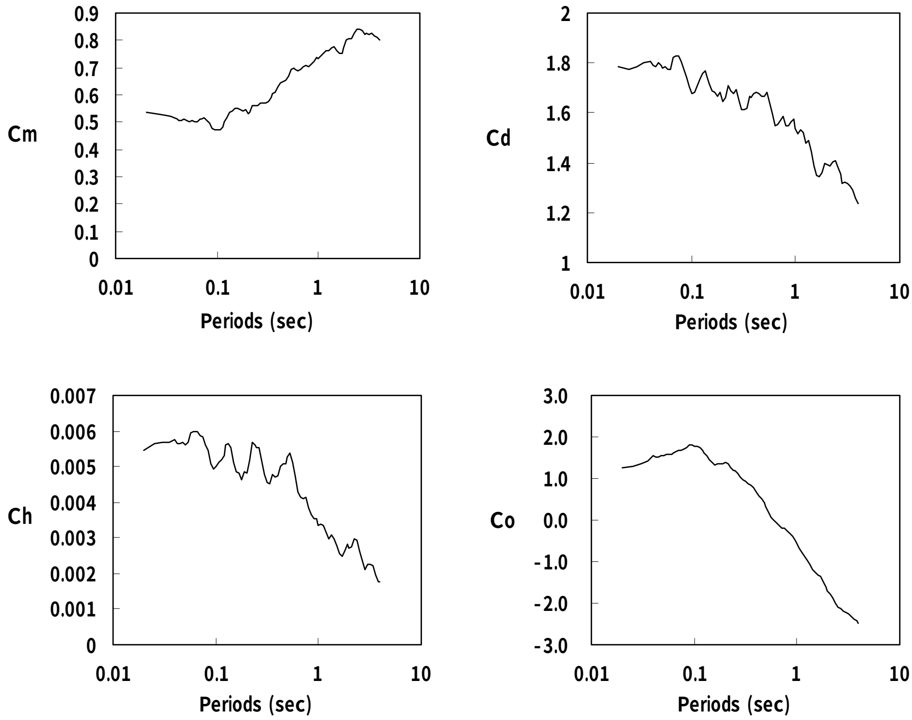
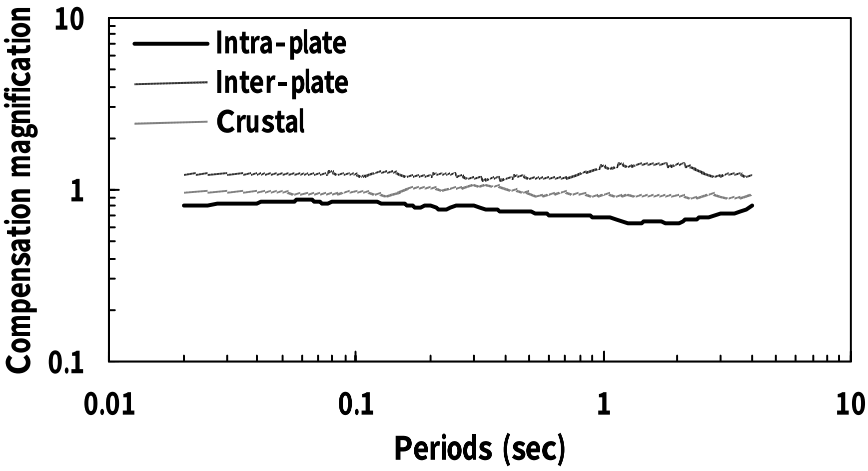


Fig 7 Relationship of average acceleration response magnification spectrum by three magnitude ranges



(a) Coefficients for attenuation equation



(b) Compensation magnification for three earthquake types

Fig 8 Coefficients for attenuation equation and compensation factors for three earthquake types

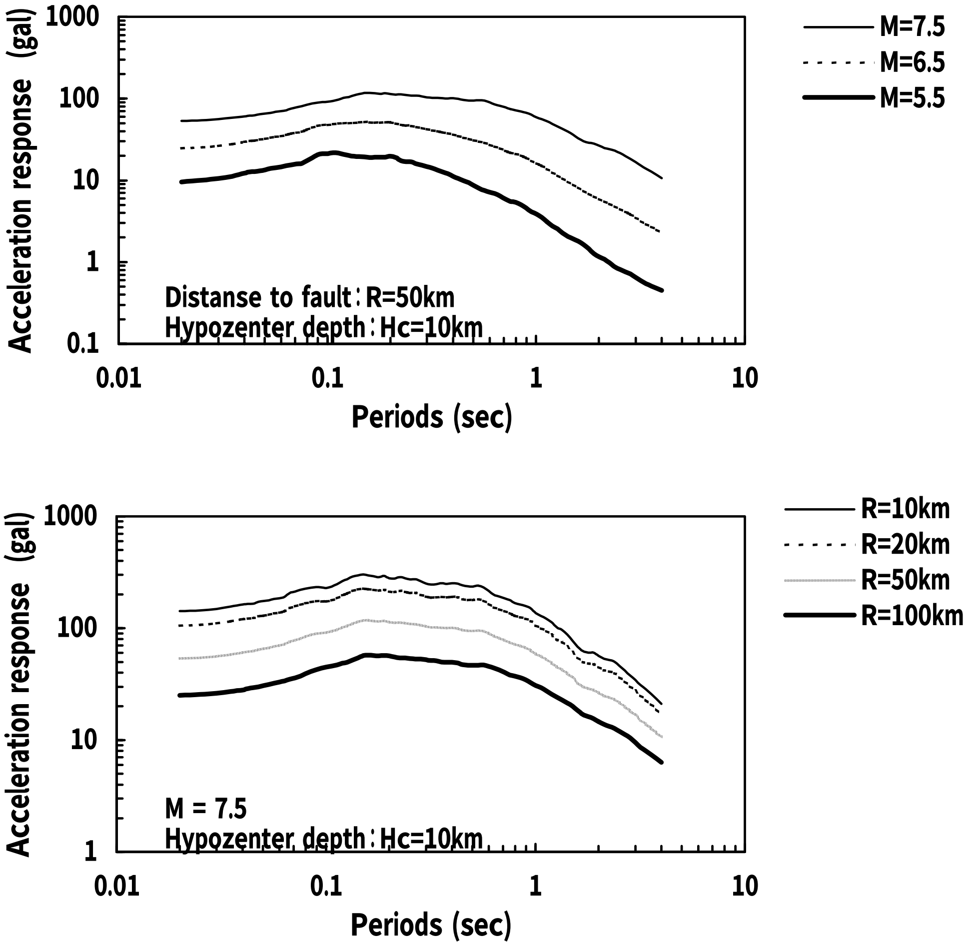
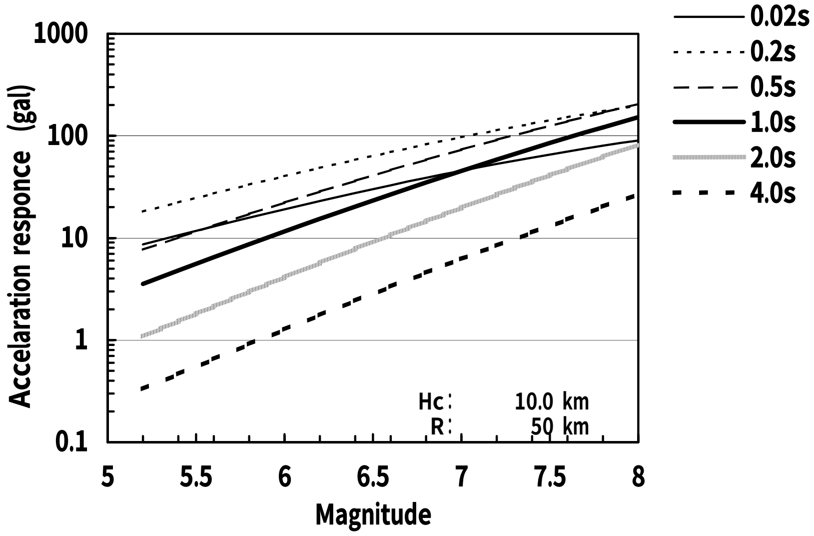
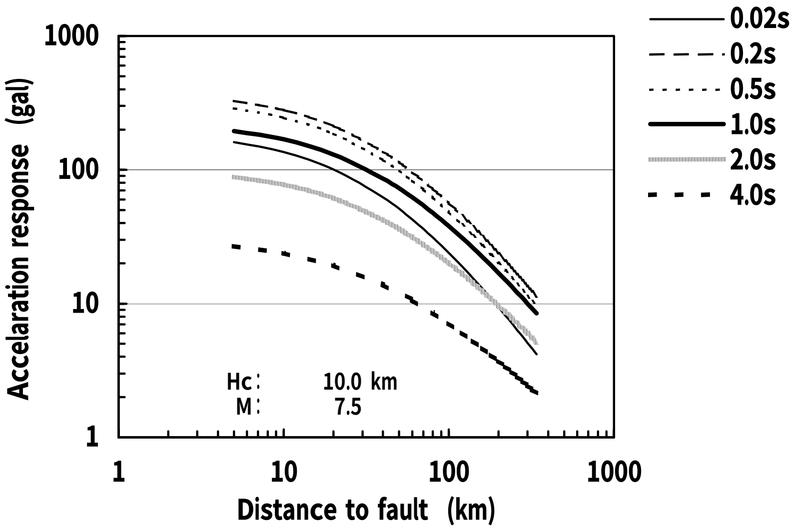


Fig 9　Presumed acceleration responses for dam foundation by attenuation equation in Ref. [7]



(a) Distance and acceleration response



(b) Magnutyude and acceleration response

Figure 10 Acceleration responses specified periods
(Depth :10km, Magnutude :7.5)