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SITE CLASSIFICATION FOR STRONG-MOTION STATIONS IN JAPAN USING H/V RESPONSE SPECTRAL RATIO

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SUMMARY

Having a reliable site classification scheme is vital for the development of robust strong-motion attenuation models. We discuss a promising site classification scheme based on strong-motion data from Japan. We assigned site classes for those K-net sites where boreholes reached either to rock or to stiff soils with shear-wave velocity of 700m/s or larger, using four site classes defined by dominant site period. The response spectral ratios of the horizontal and vertical components (H/V) of earthquake records from these sties were found not to be strongly affected by JMA magnitude, hypocentral distance, and focal depth for all site classes. We used H/V ratios for records from the classified K-net sites to establish a site classification index using the mean spectral ratios and the standard deviations of the ratios. Using the index, we were able to classify both K-net stations with soil layers thicker than 20m and other strong-motion stations in Japan. The site amplification factors calculated from the site class terms based on the new site classification are consistent with the period bands defined for these site classes.

INTRODUCTION

An attenuation relation for strong ground motion is an important component of seismic hazard studies, and is also used by engineers to estimate the forces and/or displacements to which engineering structures might be exposed. Variability of an attenuation model is usually large, often a factor of two for one standard deviation of model prediction. The sources of variability include:

(a) the simple measure of earthquake strength, usually by a single parameter of moment magnitude;
(b) the simple representation of seismic wave propagation by geometric and anelastic attenuation;
(c) the simple measure of source distance by a shortest straight line distance between a particular site and a rupture plane, or hypocentral distance when a fault rupture model is not available; and
(d) the simple representation of site effects by site classes with each site class being assigned according to a simple parameter, such as the average shear-wave velocity of the top 30m (BSSC

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[1]) or site dominant periods which are calculated from the travel time of the vertically propagating shear waves according to the theoretical modeling of a uniform soil layer on top of the bed rock which has a shear wave velocity over 600-700m/s (this kind of bed rock is referred to as engineering bed rock in Japan).

In a probabilistic seismic hazard analysis, both the mean values and the prediction uncertainties of an attenuation model are utilized. The amplitude of uncertainties can have as much impact as the level of mean prediction on the ground motion estimates. High prediction uncertainties lead to high levels of probabilistic ground motion estimates.

Site conditions have profound effects on the ground surface motions at soil sites. The ground motion amplification factors of soil sites with respect to rock sites are between 1.5 and 3.0 on average (see Figure 8a). Inappropriate modeling of site effects can introduce large variability into attenuation models. When site information is not available, many researchers from Japan attempted to use individual site correction terms for each strong-motion recording station, in order to overcome the difficulties in site condition modeling (Molas and Yamazaki [2], Kobayashi et al [3] and Takahashi et al [4]). A typical form of the attenuation function for these models often used is:

$$\log_{10}[(SA_{i,j}(T)] = a\ M_i - b\ x_{i,j} - \log_{10}(x_{i,j} + r_o) + e\ h + S_k \qquad (1)$$

where y is either peak ground acceleration (PGA) or 5% damped acceleration response spectrum for a spectral period T, M is moment magnitude, x is source distance in km, r_o is the added distance to account for possible ground motion saturation with decreasing source distance in the near-source region and h is focal depth. S_k represents the individual site terms for all recording stations. In the Takahashi et al [4] model, there were 1332 strong-motion records from 689 strong-motion recording stations. The total number of parameters in Equation 1 was over 690 parameters. Such a large number of parameters make unbiased estimates difficult to obtain.

Molas and Yamazaki [2] used the two-stage regression method for the JMA data set and they found that the number of dummy variables, i.e., event terms (one for each earthquake) and individual site terms for 76 stations, possibly resulted in a singular normal matrix. They used an iterative method to overcome this problem but an ill-conditioned normal matrix does not always lead to unbiased estimate (Press et al [5], Section 14). Another possible drawback to this approach is that model prediction error and some of the source effects may propagate into individual site terms. Estimating source type effects was attempted in the Takahashi et al [4] studies by summing up inter-event residuals for a group of events with known source types, i.e., crustal, interface and intra-slab events (unpublished results) but conclusions were not clear. When the number of records for a particular station is small (one or two records), the data from this station has little statistical power for deriving the coefficients of model parameters associated with source and path terms, as any residuals due to source and path terms can propagate into the estimate of the individual site terms for the particular station, resulting a nearly perfect fit for the records from it. When individual site correction terms were used, site class terms were derived from the mean values of individual site terms for each group of the sites with known site class. The standard deviation of site class terms would reveal the extent of error propagation from uncertainties of source and path parameters and the variability of site class terms. Figure 1(a) shows that the inter-event error of the Takahashi et al model [4] is just over 0.3 for periods up to 1s and decreases to about 0.2 at 5s period, while the inter-event error for the Takahashi et al model [6] in Figure 1(b) is about 0.4 for most periods and close to 0.5 at 0.1s period. Note that source type effects were not accounted for in the Takahashi et al (2000) study[4] and the inter-event errors are expected to be smaller or at least similar to those of the Takahashi et al (2004) model [6] in which source types were accounted for. The smaller inter-event error in the Takahashi et al 2000 study may be a result of error propagation from source terms into individual site terms. The intra-event error in the Takahashi et al 2000 study [4] is also considerably smaller than that in the Takahashi et al 2004 model [6], again a possible result of error propagation. The error calculated from a sub-set of the Takahashi et al 2000 [4] data set for those sites with site classes is quite large, between 0.6 and 0.75 as shown in Figure 1(a), comparable with the intra-event error in Figure 1(b). The total error, which equals the square root of the sum of squares for inter-event, intra-event error and the errors associated with site class terms of the Takahashi et al 2000 study [4] is considerably higher than the total error shown in Figure 1(b).

A significant amount of effort on collecting geotechnical information for recording stations has been expended in Japan. The collection of such information is difficult and expensive. Before the K-net strong-motion network was in operation, only a handful of recording stations, all operated by Port and Harbour Research Institute, had measured shear-wave velocity profiles. As part of the K-net project, shear-wave velocities were measured for most stations, but only down to 20m depth. For many stations this is unlikely to have been deep enough to reach very stiff soils or bedrock. Some of the Kik-net (a recently established network) stations in Japan have shear-wave velocity profiles down to bed rock basement.

There have been a number of alternatives for estimating site effect, such as Nakamura's ratios using the spectral ratio between the horizontal and vertical components (H/V) of recorded ambient microtremor, and receiver's function method, using the spectral ratios of the horizontal and the vertical components of an earthquake record. Field and Jacob [7] showed that the H/V ratio of earthquake records in an S-wave window could reveal the overall frequency dependence of site response, while the spectral ratio in the P-wave window had little correlation with the site response. A comparison of the two approaches was made by Lachet et al [8] and they concluded that the agreement between receiver's function, the Nakamura's ratios and the classical spectral ratios between a soil site and a reference site (rock) is satisfactory in the amplified frequency band. They also concluded that the receiver's function method gave only partial information on the site effects, such as the fundamental resonance frequency, and that the H/V ratios systematically under-estimated the spectral ratios of a soil site to the reference rock site.

For assigning site classes for strong-motion stations, an approximate approach may be appropriate because each site class is likely to contain sites with different response characteristics. The receiver's function approach, in conjunction with the limited geotechnical information of the K-net strong-motion network, and the large number of strong-motion records (the majority of which are too small to be used in attenuation modeling), could provide a quick and satisfactory means for classification of strong-motion sites.

One of the classification schemes commonly used in Japan is based on geotechnical descriptions of soil types, thickness of surface soil layers of alluvium and diluvium, and site natural periods (Molas and Yamazaki [2]). The site periods for defining site classes are given in Table 1, along with the corresponding average shear-wave velocity of the top 30m (using 0.25 times the site period in each site class as the shear-wave travel time in the top 30m soil layers) and the NEHRP site classes (BSSC 2000 [1]). The natural period range of each site class provides a set of convenient parameters, if it can be estimated. Here we assume that the natural site period can be estimated as four times the S-wave travel time in the soil layer, with an implicit assumption that the site can be represented by a single soil layer with a constant shear wave velocity. As soil descriptions are not used in the present study, the four site classes are referred to as SC I, II, III and IV, instead of rock, hard soil, medium soil and soft soil sites.

Table 1 **Site class definitions used in the present study and the approximately corresponding NEHRP site classes (BSSC 2000 [1])**

Site classes	Site natural period (s)	Average shear-wave velocity	NEHRP class
SC I: (Rock/stiff soil)	$T_G < 0.2$s	$V_{30} > 600$ m/s	A+B
SC II: (Hard soil)	$0.2s \le T_G < 0.4s$	300 m/s $< V_{30} \le 600$ m/s	C
SC III: (Medium soil)	$0.4s \le T_G < 0.6s$	200 m/s $< V_{30} \le 300$ m/s	D
SC IV: (Soft soil)	$T_G \ge 0.6$s	$V_{30} \le 200$ m/s	E

STRONG-MOTION DATA SET

A total number of 5400 records from 122 earthquakes recorded at 872 K-net strong-motion stations were consistently processed, and a high-pass filter was used to eliminate the long period ground motions with frequency less than the corner frequency of the filter. The corner frequency of the filter was determined for each record by using the method of Kobayashi et al. [3]. The distributions of the records and the earthquakes with respect to magnitude, hypocentral distance and focal depth are shown in Figure 2. The focal depth is the JMA depth which contains significant errors (Kobayashi et al [3]), especially for the shallow events. The zero depth of a few events in Figure 2(b) actually implies undetermined focal depth. The JMA locations for many of the earthquakes also contain considerable errors ((Kobayashi et al [3]) and therefore the hypocentral distances in Figure 2(a) are not precise. These problems of the data set do not have any adverse effects on the present study.

In the conventional receiver's function method, Fourier spectra calculated in an S-wave window for a short duration, such as the 2-10s suggested by Lachet et al [8], were used. Smoothing the Fourier spectra is essential in the computation of spectral ratios so that smoothed spectral peaks corresponding to the site response characteristics can be extracted from the un-smoothed spectra with many spikes. The smoothing method and the extent of the smoothing have to be consistent for all records if the amplitude of the spectral ratios is to be used. It is also essential that a large number of records be used so that any spikes due to causes un-related to the site response can be removed by averaging the spectral ratios of a number of records. When a large number of stations need to be classified, the amount of effort and time are extremely large. In the present study, an alternative method was employed.

Instead of Fourier spectral ratios, H/V ratios of 5% damped response spectra can be used (Yamazaki and Ansary [9]). The un-damped response spectrum of an earthquake record is very similar to the Fourier spectrum and the damping used in calculating a response spectrum has a smoothing effect. For a damping ratio of 5% the response spectra have few spikes, and the smoothing effect is similar for all records if the same damping ratio is used. For both the vertical and horizontal components of most earthquake records, the peak values of spectral acceleration, i.e., the peak total accelerations for single-degree of freedom oscillators, nearly always occur after the arrival of S-waves, except for very long and very short spectral periods. For very long periods, the peak value of the total acceleration may occur during the late arrivals of surface waves, and for very short period the peak values may occur before the time of S-wave arrival. For the vertical component, the peak total acceleration can occasionally occur before the S-wave arrival. These analyses suggest that H/V ratios of 5% damped response spectra can also be used in assessing site response characteristics, with the advantage that no smoothing is required. This method does not guarantee that only the S-wave portion of a record contributes to the response spectra, but the greatly reduced amount of effort in calculating spectral ratios makes it possible to use all available records. Any additional approximation introduced by using response spectral ratios is expected to be offset by the effect of averaging over a large number of records.

VARIABILITY OF SPECTRAL RATIOS

Of the K-net stations, about 325 can be classified according to the definition of Table 1. At these stations, stiff soil or "bedrock" having a shear-wave velocity over 700m/s, is reached at a depth of 20m or less. A further 20 stations for which the soil shear-wave velocity is over 650m/s at 20m depth and the shear-wave velocity gradient suggests that the shear-wave velocity is likely to reach 700m/s within a few meters depth below 20m, also were classified. Mean spectral ratios and standard deviations for about 240 classified stations are shown in Figures 3a and 3b. The amplitudes and the shapes of the mean H/V response spectral ratios are remarkably different for the four site classes. For SC III and IV classes the standard deviations are reasonably small at the peaks of the mean H/V. The periods of the peaks in the spectral ratios are consistent with the site class definitions, at 0.15s, 0.25s 0.4s and 0.8s for SC I, SC II, SC III and SC IV sites respectively. The largest standard deviation is about 0.6 in natural logarithm scale at 0.4s period for SC IV sites. The standard deviation for SC II sites is about 0.55 at 0.25s.

Table 2 Numbers of records in each magnitude group

	5.4 or less	5.5-5.9	6.0 or larger	all data
SC I	953	467	259	1679
SC II	778	318	210	1306
SC III	40	24	17	81
SC IV	230	70	43	343

Tables 2-4 show the numbers of records in each site class for different magnitude, hypocentral distance and focal depth groups.

Figure 4 shows the effect of magnitude on the H/V ratios for the four site classes for different magnitude. The variation of spectral ratios between different magnitude ranges is reasonably small, with the largest overall difference being from the SC I site data for $M_{JMA} > 5.9$, see Figure 4(a). The peak ratios for $M_{JMA} > 5.9$ group of the SC III sites is moderately larger than those of the other magnitude ranges (Figure 4(c)). SC III sites have the smallest number of records and have only 17 records in the $M_{JMA} > 5.9$ group. The small number of records from SC III sites can lead to the apparently different spectral ratios compared with those of the other site classes.

Table 3 Numbers of records in each hypocentral distance group

	100km or less	100-160km	160km or larger	All data
SC I	944	477	258	1679
SC II	362	564	380	1306
SC III	23	35	23	81
SC IV	105	125	113	343

Table 4 Numbers of records in each focal depth group

	30km or less	30-60km	60km or deeper	All data
SC I	491	653	535	1679
SC II	357	493	456	1306
SC III	31	24	26	81
SC IV	97	118	128	343

Figure 5 shows the H/V spectral ratios for the four site classes for different hypocentral distance ranges. Again the variations of spectral ratios in different distance ranges are reasonably small. For records in a distance over 160km the spectral ratios at the descending branch (on the right hand side of the peak ratio) are smaller than those of the other distance ranges for all four site classes.

Figure 6 shows the spectral ratios for the four site classes for earthquakes in different JMA focal depth ranges. Kobayashi et al [3] found that the JMA focal depth estimates may be unreliable, and for some of the events focal depth was un-determined but set to zero. However the JMA depths of deep events were reasonably consistent with those estimated by the other organizations. The curves of spectral ratios in the ascending branch (on the left hand side of the dominant peak) are very similar for all distance ranges and all site classes, while on the descending branch (on the right hand side of the dominant peak) records from deep earthquakes tend to have higher spectral ratios than those of shallow earthquakes for all site classes. For SC III sites, the peak spectral ratios from earthquakes in the depth range of 30-60km are much larger than for the other depth ranges.

Standard deviation of the spectral ratio also is an important parameter in this study, and the variations of the standard deviation with respect to source distance and focal depth are shown in Figure 7 for SC II and SC IV sites. Figures 7(a) and 7(b) show the effect of hypocentral distance ranges on the standard deviation of the H/V ratios for SC II and SC IV site classes, respectively. The effects of hypocentral distance range are moderate for both site classes, and records from distant events have the smallest standard deviation in the period ranges of 0-0.2s and 0.7-3.0s for SC II sites and beyond 1.0s for SC IV sites. The standard deviations of SC II and SC IV sites are not strongly affected by focal depth ranges, especially for SC II sites, as shown in Figures 7(c) and 7(d). The variations of standard deviation with magnitude range are similar to those shown in Figure 7.

Effects of gradient of shear-wave velocity with respect to depth in the top 20m and the angle between the straight line from a site to the hypocenter of an event and the horizontal direction (an approximation to the angle of incidence of the seismic waves at the basement bed rock with a shear-wave velocity exceeding 3km/s) were found to be negligible.

The overall variabilities of mean spectral ratios and standard deviations with respect to magnitude, hypocentral distance and focal depth are not very large and using the mean spectral ratios and the standard deviation of all data would not introduce excessively large errors, considering the approximate nature of site classification used for developing strong-motion attenuation models.

SITE CLASSIFICATION METHOD

Figure 3(a) shows that the spectral ratios have peaks within the range of site periods that have been defined for each site class (Table 1), and that the shapes of spectral ratios with respect to spectral periods are distinguishably different for each site class. For many sites, the average H/V spectral ratio of a number of records can be quite spiky, even when the number of records is reasonable, for example, 5 or more. The period of the first (long period) dominant peak is commonly taken as the natural period for the sites, but we find that this method is good only for some of the SC III and SC IV sites. For many sites it is usually not possible to pick a dominant peak and to rely on the spectral period at the dominant peak of mean H/V spectral ratios for site classification would not be reliable. In the present study, the H/V spectral ratios of all periods that spectral ratios were calculated are used to improve the accuracy. Further improvement can be expected if the variability of the H/V ratios is also accounted for. We designed a site classification index (SI),

$$SI_k = 2\sum_{i=1}^{n}\Phi\left(-\frac{\mathrm{abs}[\ln(\mu_i)-\ln(\bar{\mu}_{ki})]}{\sigma_{ki}}\right) \qquad (2)$$

where:
k - site class number
n - the total number of periods
$\Phi(\,)$ – normal distribution function
μ_i - the mean H/V ratio for the site of interests for the i^{th} period

$\overline{\mu}_{ki}$ - the mean H/V ratio for the k^{th} site class averaged over all sites of the data base for the i^{th} period
σ_{ki} - the standard deviation of the H/V ratios for site class k and ith period

SI is not strictly defined in the sense of probability theory but is an index for site classification only. For a particular period, SI equals unity if the mean H/V ratio for a site is equal to the mean H/V ratio of a particular site class, otherwise it is less than 1.0. The standard deviation of the spectral ratios serves as a weighting so that the spectral ratios with a small standard deviation for a particular period will contribute more to SI than the periods that have a large standard deviation. For a particular site, SI was calculated for each site class and the site class with the largest value of SI was assigned to this site. This method is essentially based on amplitudes, and the shapes of H/V ratios with respect to period, and accounts for the variability of the spectral ratios. Note that spectral ratios at zero seconds, i.e., for peak ground accelerations, are not used, as ground-motions from an undesirably large frequency band contribute to peak ground accelerations.

We applied this method to all K-net recording stations, including those stations that were not part of the group of stations used in deriving the mean spectral ratios and the standard deviations. The results showed that correct site classes were estimated for just over 60% of the stations for two groups, i.e., the stations that were used in calculating the spectral ratios and their standard deviations, and the others that had site classifications but which were not used in computing the mean spectral ratios. The similar level of accuracy for the two groups was not surprising because of the way that the standard deviation for these spectral ratios was used. Over 90% of the stations were estimated within a margin of one class. This is a significant improvement over the method based on only the geological descriptions over an area where a strong station is located. The percentage for correct estimates of site classes is about the same for stations with a small number of records, for example 3, though the spectral ratios are less spiky when the number of records is large.

For those K-net stations where bed rock was not reached at a depth of 20m, an additional correction procedure can be used. For example, if SC II class is assigned to a station by using H/V spectral ratios, but the shear-wave travel time calculated from the velocity profile down to 20m suggests that the station should have a natural period larger than the natural period specified for SC II class, then the site class based on the travel time in the top 20m soil is used.

We classified a large number of strong-motion stations in Japan that we collected records from. Site class terms were then derived from individual site terms of the attenuation model by Takahashi et al. [4], by taking the mean values of individual site terms for each site class. Site amplification factors were then evaluated and are shown in Figure 8. By taking site amplification factors, any effect from potential errors contributed by source types and faulting mechanisms (not modeled in Takahashi et al. study [4]) would be largely eliminated, on the assumption that similar amounts of errors from un-modeled source types are evenly distributed in the site terms that are used to calculate site factors. The site amplification factors derived from individual site terms of Takahashi et al. [4] but using the new site class are very different from those in Figure 8(b) where site amplification factors were derived from the mean site terms of Takahashi et al. [4] but using site classes determined mainly by site geological descriptions in that study. It is obvious that site amplification factors in Figure 8(b) are not consistent with the defined site natural period bands. For example, SC III sites appear to have a peak amplification at about 1.0s period, which could be due to misallocation of many SC IV sites to the SC III class. The site amplification factors derived according to the new site classes are consistent with the period ranges that define the site class. All three site classes show a trough at about 0.1s which can be interpreted as the period of the spectral peak for SC I sites. The amplification curve for SC II sites shows a broad-band amplification at periods beyond 0.15s. SC III class shows a peak amplification at about 0.5s which lies in the middle of the dominant periods, 0.4-

0.6s, for this site class. The amplification curve for SC IV sites has a peak at 0.9s that is also reasonably consistent with the definition of this site class being dominant periods larger than 0.6s. These results validate the appropriateness of the site classification method presented here.

The new site classes were used by Takahashi et al 2004 [6] to derive an attenuation model that uses site class factors and accounts for source types and faulting mechanisms for crustal earthquakes. Site amplification factors for soil sites with respect to SC I sites from that study are presented in Figure 9(a). The amplification factors are similar to those in Figure 8(a) and are consistent with the period range used for site classification (see Table 1)

H/V ratios are known to underestimate amplification factor derived from spectral ratios of a soil site and a reference rock site [7]. One way to verify this observation is to calculate "pseudo-site amplification factors" by using the mean H/V ratios shown Figure 3(a), i.e, using the H/V ratios for a soil site class divided by the H/V ratios of the SC I site class. Figure 9(b) shows the "pseudo-site amplification factors" which have similar shapes to those of Figure 9(a) but with much reduced amplitudes at the peaks. Figure 9(b) suggested that H/V ratios and the "pseudo-site amplification factor" can not be used to estimate the amplitude of site amplification.

Note that the method presented in this study is based on H/V spectral ratios only, and other effects, such as local topography where the recording station is located, cannot be identified. These effects could make the site class assigned to a particular site inconsistent with the shear-wave velocity profile at the site.

The plausible results presented in this study suggest that H/V spectral ratios can be used to assign site classes for developing strong-motion attenuation models. Caution must be exercised if this method is to use to classify a particular site for the purpose of determining seismic design load from a design code, as the probability of incorrect classification may be too high.

If the mean spectral ratios and the standard deviation for each site class are calculated according to a similar, but different from those of Table 1 in details, site classification scheme, the present method may assign most sites identical site classes to those in the present study.

CONCLUSION

The following conclusions can be reached in the present study;

1. Using the prediction errors from two attenuation models, one using individual site correction terms and the other using site class terms, we demonstrated that error propagation from source and path terms into site terms when individual site correction terms are used in developing strong ground motion models;
2. H/V spectral ratios of 5% damped response spectra were calculated for about 5400 earthquake records from 870 stations of K-net strong-motion network in Japan. For about 325 K-net stations where shear-wave velocities were available down to engineering bed rock, site classes were determined according to a classification scheme based on site dominant periods, commonly used in Japan;
3. The mean H/V ratios calculated for the K-net recording stations with site classification showed remarkably different amplitudes and shapes for different site classes. The mean spectral ratios and the standard deviations of the spectral ratios are not strongly affected by JMA magnitude, hypocentral distance and focal depth;
4. A site classification index based on the mean H/V spectral ratio amplitudes and the corresponding standard deviations was established as a practical tool for estimating site classes for strong-motion stations from which earthquake records are available; and

5. Site classification was carried out for many strong-motion stations in Japan and we successfully verified our methodology by comparing site amplification factors from the site class terms of an attenuation model developed in a separate study and the mean site terms of a published attenuation model which used individual site terms.
6. The amplitude of H/V spectral ratios may not be used to assess potential site amplification for an engineering site for the purpose of determining seismic load for the structure on the site, because the probability of assigning incorrect site class to a single site may be too large.

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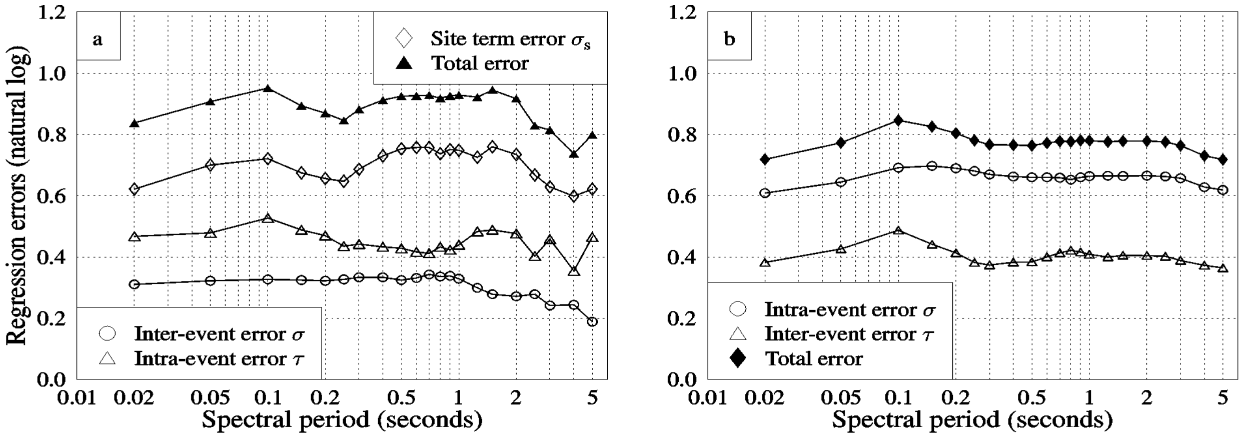

Figure 1. Standard errors of two attenuation models, (a) the Takahashi et al 2000 study [4], and (b) the Takahashi et al 2004 study [6]

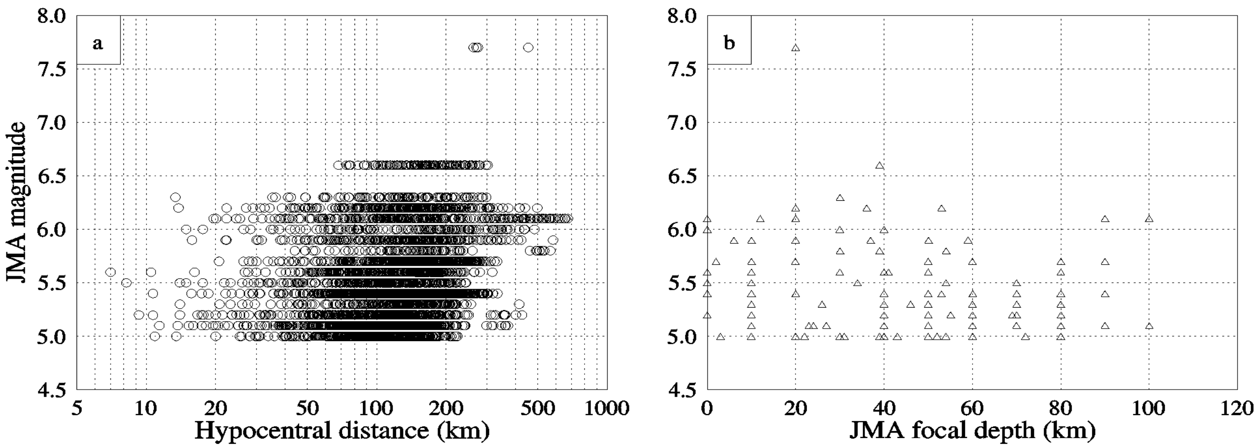

Figure 2. Distribution of data used in the present study, (a) recordings with respect to magnitude and hypocentral distances, and (b) events with respect to magnitude and focal depth

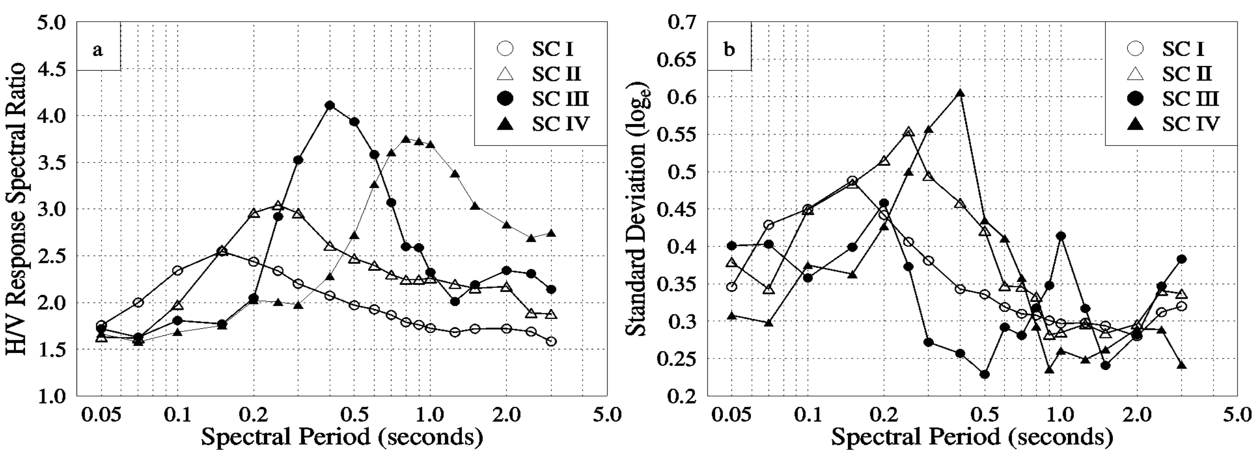

Figure 3. Mean response spectral ratio (H/V) (a), and corresponding standard deviations of the ratios (b), for all data from the K-net stations for which site classifications are available

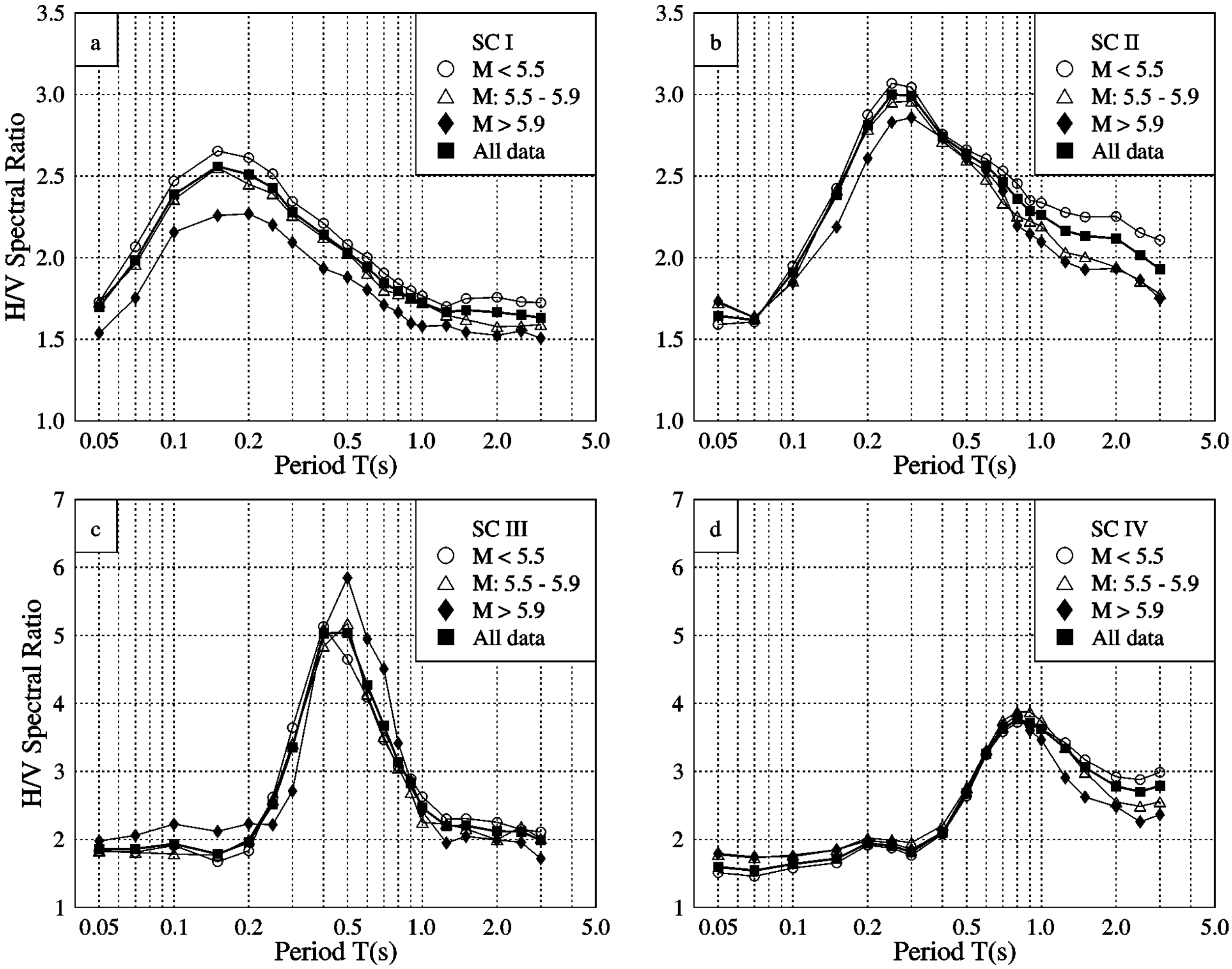

Figure 4. Variation of H/V spectral ratio with magnitude for four site classes

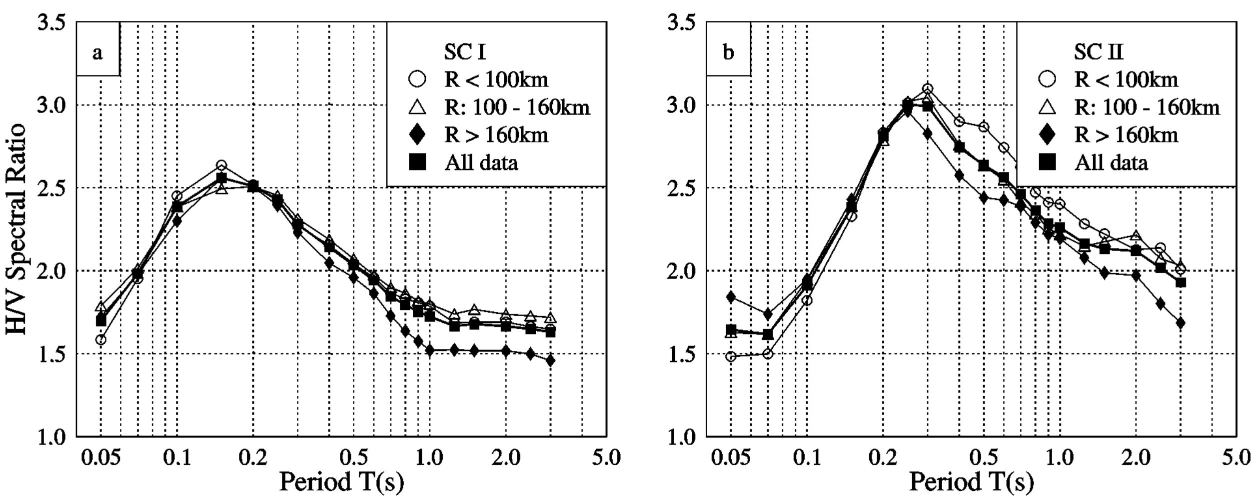

Figure 5(a) and 5(b). Variation of H/V spectral ratio with hypocentral distance for SC I and SC II site classes

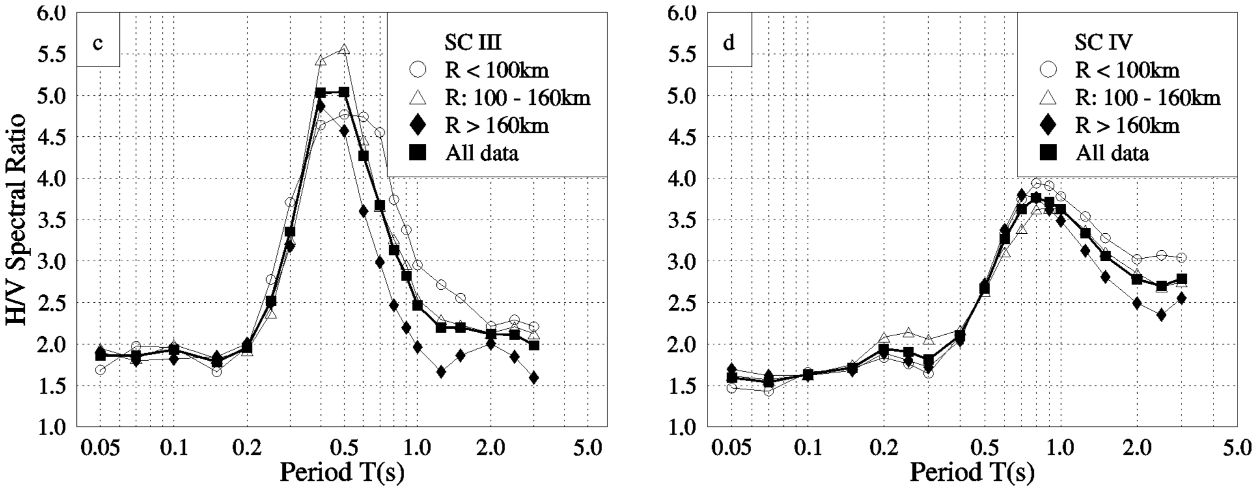

Figure 5(c) and (d). Variation of H/V spectral ratio with hypocentral distance for SC III and SC IV site classes

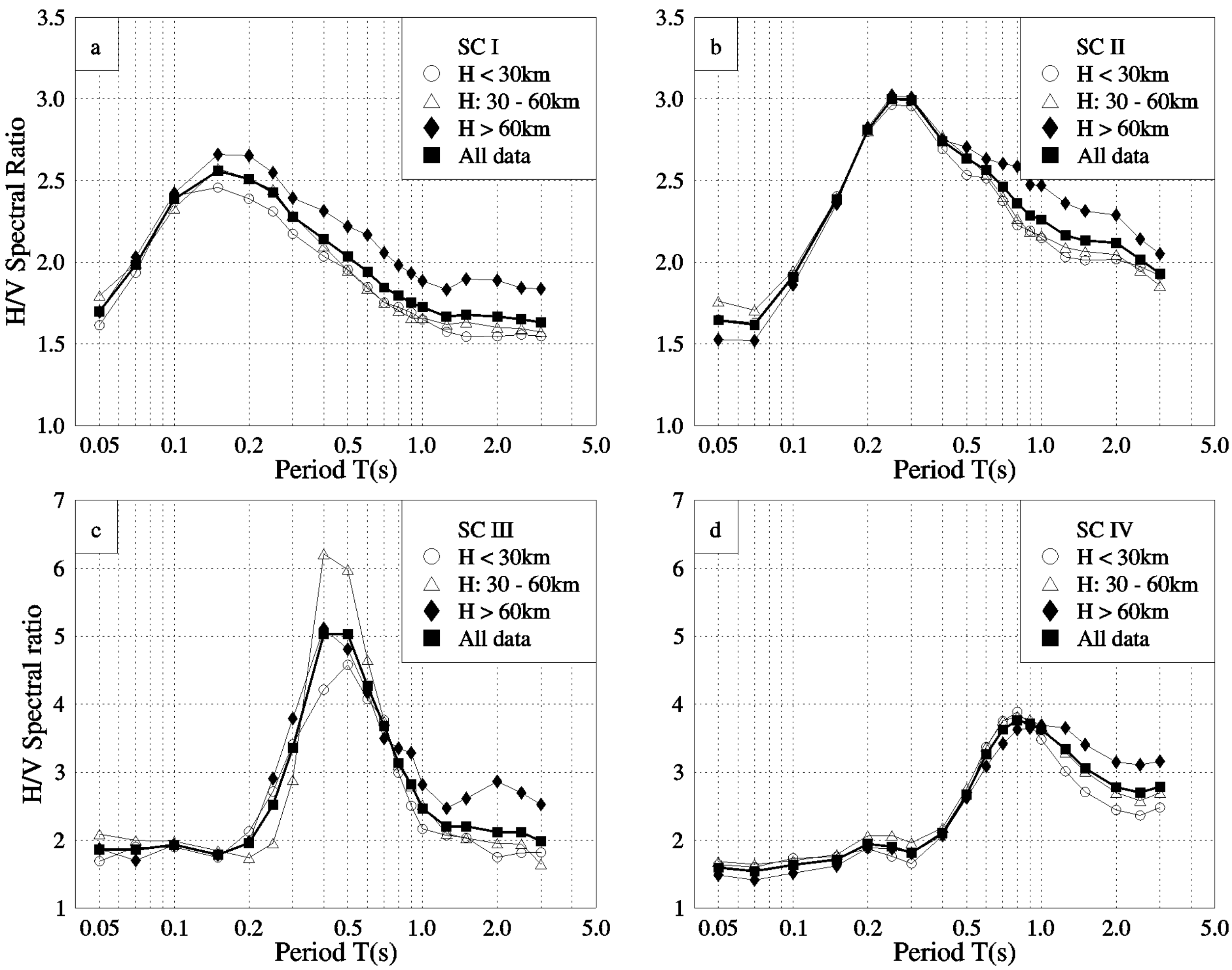

Figure 6 Variation of H/V spectral ratio with depth for four site classes

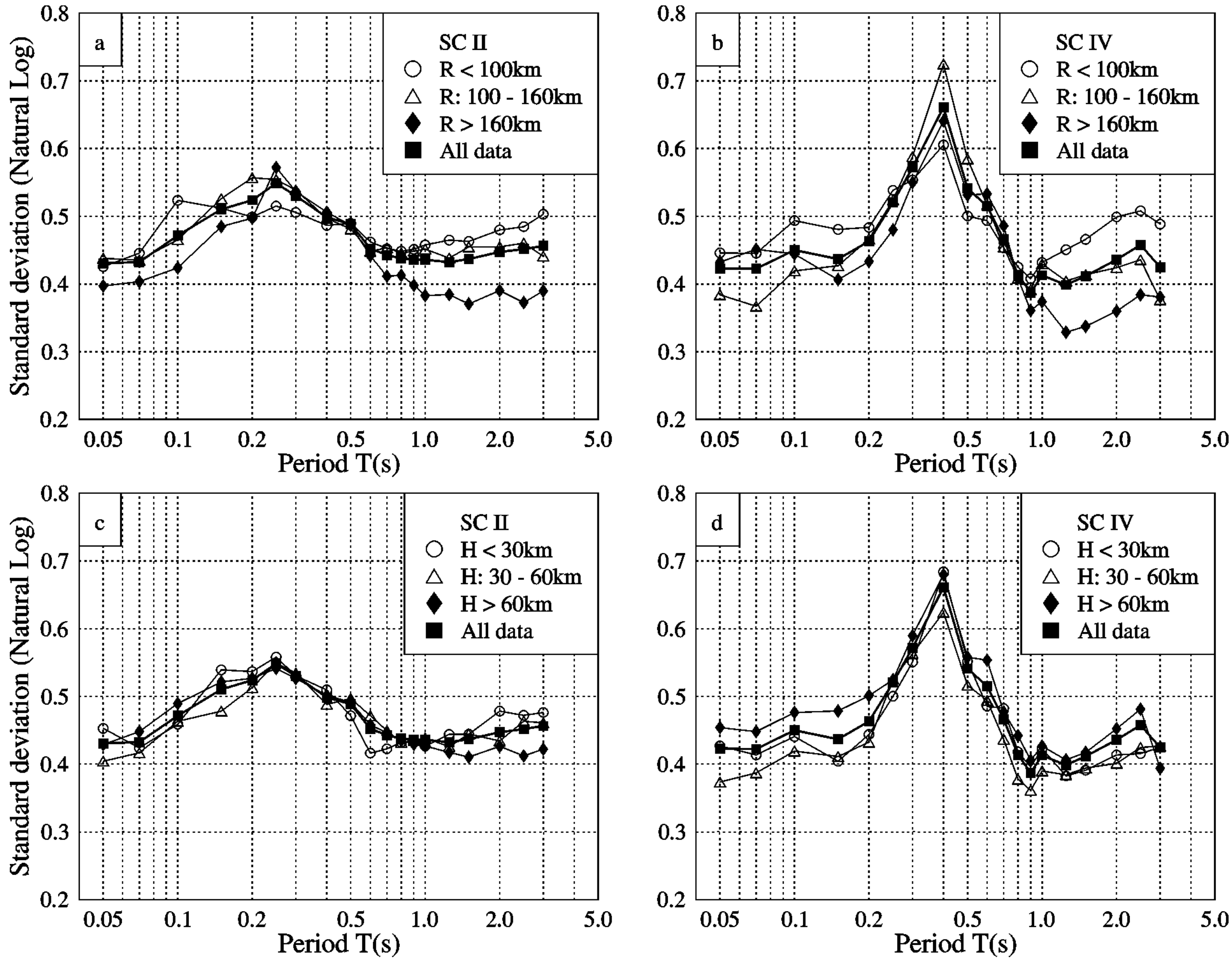

Figure 7. Variation of standard deviation of H/V spectral ratio with hypocentral distance for (a) SC II sites and (b) for SC IV sites, and with respect to focal depth for (c) SC II sites, and (d) SC IV sites

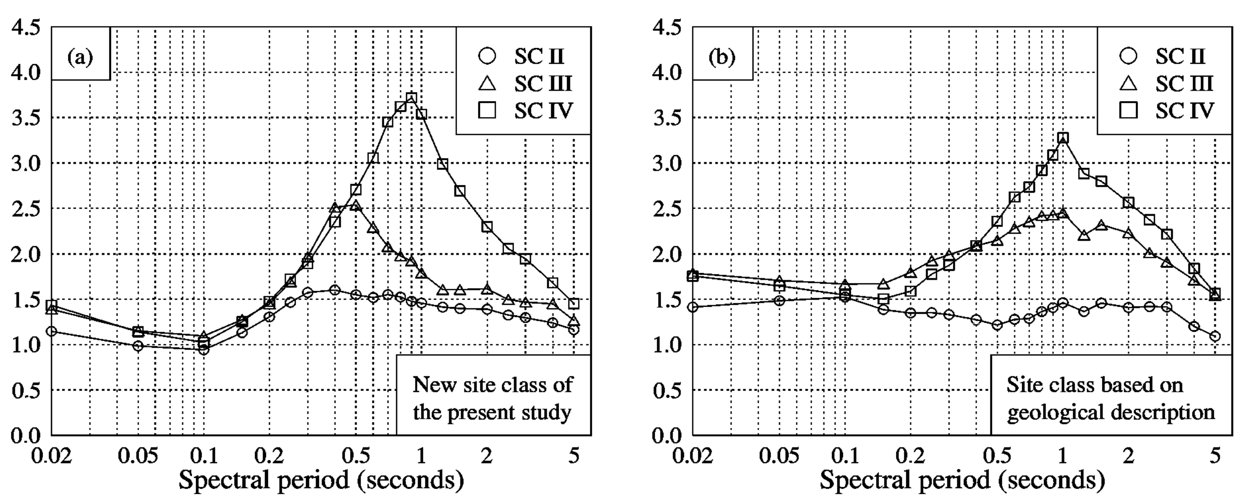

Figure 8. Site amplification factors derived from Takahashi et al 2000 study (a) using the site classes obtained in the present study, (b) using site classes assigned according to geological description only

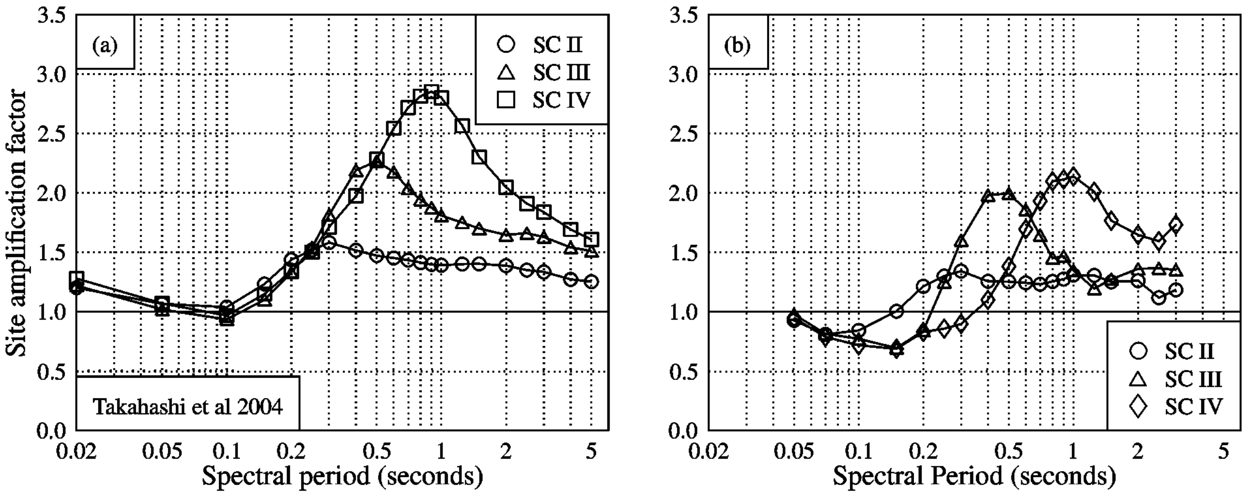

Figure 9. Site amplification factors derived (a) from Takahashi et al 2004 [6] study using the site classes of the present study, (b) "pseudo-site amplification factor" from the H/V ratios shown in Figure 3(a)